# RENEWABLE ENERGY IN THE EIGHTIES: NEEDS FOR FURTHER R&D

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# HEARINGS

(Including a Symposium on Renewable Energy in the Eighties: Needs for Further Research, Development and Demonstration)

BEFORE THE

SUBCOMMITTEE ON
ENERGY DEVELOPMENT AND APPLICATIONS

OF THE

COMMITTEE ON
SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

NINETY-SEVENTH CONGRESS

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*On assignment to Budget Committee for 97th Congress.

# LETTER OF TRANSMITTAL

House of Representatives,
Committee on Science and Technology,
*Washington, D.C., October 6, 1982.*

*To All Members of the Committee on Science and Technology:*

The Subcommittee on Energy Development and Applications, as part of its oversight activities in the 2d session of the 97th Congress, examined research and development needs in this decade for renewable energy technologies. Because there has been much controversy recently about the respective roles of the Federal Government and the private sector in technology development, the Subcommittee held two events to help define the outstanding R&D issues for renewable energy in order to better delineate Federal and private sector responsibilities. The proceedings of these meetings are published together in this volume under the title "Renewable Energy in the Eighties: Needs for Further R&D".

The first meeting was a symposium held on May 28, 1982 at the U.S. Pavilion at the 1982 World's Fair, Knoxville, Tenn. This location was most fitting as energy was the Fair's primary theme. The symposium participants provided a comprehensive picture of solar, geothermal and biomass technologies from the perspective of the southeastern region.

The second meeting was a hearing held on July 28, 1982 in Washington, D.C. This hearing dealt with the more specialized and complex issues surrounding R&D needs for the solar electric technologies. Expert witnesses included individuals from national laboratories, universities, utility groups, and industry.

I am certain that the proceedings of the seminar and hearing will contribute to the information base that we require to ensure a balanced, properly focused energy R&D policy in the years ahead.

Sincerely,

Don Fuqua,
*Chairman.*

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# SYMPOSIUM ON RENEWABLE ENERGY IN THE EIGHTIES: NEEDS FOR FURTHER RESEARCH, DEVELOPMENT, AND DEMONSTRATION

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FRIDAY, MAY 28, 1982

SPONSORED BY THE
COMMITTEE ON SCIENCE AND TECHNOLOGY,
SUBCOMMITTEE ON ENERGY DEVELOPMENT AND APPLICATIONS,
*Washington, D.C.*

The subcommittee met, pursuant to call, at 9:45 a.m., in Western Plaza, U.S. Pavilion, the 1982 World's Fair, Knoxville, Tenn., Ezra Heitowit (deputy subcommittee staff director) presiding.

Mr. BEACH. Ladies and gentlemen, my name is Al Beach and I am the Deputy Commissioner General for the U.S. Government Pavilion which you are now visiting. I want to say a few words of welcome here for your symposium today.

Distinguished members of the staff of the subcommittee of the Committee on Science and Technology of the House, and those who have come here to present their findings and their papers to the panel we are very glad that you are here today. We hope that while you are here you will be able to visit the pavilion, because some of your people who could not come today, I am sure were on the committees that decided that the funds for this pavilion would not be appropriated.

We have tried in our planning to present to the American public, and to the world, an accurate exhibit about energy in the United States; where we were, where we are now, what is left, and what we might be able to do about it.

In addition to the exhibit, we have at the IMAX theater a very impressive film called "Energy, Energy" of about 24 minutes, which we also hope you might have a chance to visit. I am speaking on behalf of Mr. Joe Rogers, who is the Commissioner General of the U.S. Pavilion, and of course for the Secretary of Commerce, again, welcome, we are glad you are here.

Thank you for coming.

Mr. LAMBERT. Mr. Chairman, my name is Walter Lambert, executive vice president of the 1982 World's Fair, and vice president for energy programs in the fair. In that capacity, I am pleased to welcome you and the staff of the Committee on Science and Technology as you undertake this important set of hearings on renewable energy resources.

In addition to welcoming you to Knoxville and to the 1982 World's Fair, I think it is appropriate that this hearing should be held here in the energy capital of the world. We wish you well in your search for new and sustainable energy sources.

I would like to present to the committee for your consideration the Final Communique of the International Energy Symposia Series of the 1982 World's Fair, which concluded here on this site yesterday. We believe this is an important statement for this country and the countries of the world, and we ask your serious consideration of that statement.

Welcome to Knoxville, welcome to the 1982 World's Fair, and much success in your hearings today.

[The Final Communique follows:]

# Final Communique of the 1982 World's Fair International Energy Symposia Series

The following statement attempts to express the central message from this series of International Energy Symposia, a series of three related meetings that has sought to develop some convergence of understanding of the world energy problem. It has been prepared by a small group of participants who, by virtue of their early and continuing association with the Series, can bring an integral perspective to this statement. Because the Series has been an evolving process, and because only a portion of the participants here today attended the past two Symposia, the statement may not necessarily represent the views of all who have attended this or previous Symposia sessions. Nevertheless, it is an effort to convey the sense of the Series as a whole.

## A. FINDINGS AND OBSERVATIONS

### ENERGY: THE NATURE OF THE PROBLEM.

THE THEME OF THE 1982 WORLD'S FAIR IN KNOXVILLE, TENNESSEE, IS "ENERGY TURNS THE WORLD." AND INDEED IT DOES.

ENERGY IS IMPORTANT...TO INDUSTRIAL PRODUCTION...FOR RAISING CROPS...FOR THE INDIVIDUAL IN MAKING LIFE MORE LIVABLE. THESE VERITIES NEED NO PROOF.

WE DISCOVER HOW MUCH WE NEED ENERGY WHEN WE DO NOT HAVE AS MUCH AS WE BELIEVE WE NEED. SUCH A MOMENT CAME NEARLY TEN YEARS AGO. MOST ECONOMIES OF THE WORLD HAVE NOT YET FULLY RECOVERED FROM THE 1973-74 UPHEAVAL IN WORLD OIL PRICES AND ITS AFTERSHOCKS. THE CRUCIAL ROLE OF ENERGY IN THE MODERN WORLD COULD NOT HAVE BEEN DEMONSTRATED MORE SHARPLY. EVER SINCE, WE HAVE HAD "THE ENERGY CRISIS." THOSE WHO BELIEVE THAT IT HAS BEEN "SOLVED" ARE WRONG AND ARE IN FOR MANY UNHAPPY SURPRISES.

IN THE SHORT RUN, ABUNDANT SUPPLIES OF ENERGY AT THE RIGHT TIME AND PLACE CAN NO LONGER BE TAKEN FOR GRANTED. IN THE LONG RUN, DEPLETION OF RESOURCES AND THE ADVERSE EFFECT ON THE ENVIRONMENT RAISE SERIOUS QUESTIONS OF WHERE TO TURN. THESE ARE REAL, NOT IMAGINED, PROBLEMS. FOR THE NEXT TWO DECADES WE MUST DEPEND FOR MOST OF OUR ENERGY SUPPLIES ON WHAT HAVE COME TO BE KNOWN AS THE CONVENTIONAL SOURCES. MOST OF THESE SOURCES HAVE SERIOUS DIFFICULTIES IN PRODUCTION AND USE. YET, THE PROMISE OF LOW RISK, ABUNDANT, NON-DEPLETING SOURCES AT AN AFFORDABLE

PRICE IS ON A DISTANT HORIZON. THAT IS THE CORE OF THE PROBLEM: MANAGE WISELY WHAT WE HAVE WHILE SEARCHING WITH SUSTAINED URGENCY FOR WHAT WE WANT.

NOR IS THIS PROBLEM JUST ONE COUNTRY'S CONCERN. MOST ENERGY SOURCES ARE CONCENTRATED IN WIDELY DISTANT PARTS OF THE WORLD, AND THE ACTION OF ANY ONE COUNTRY TOUCHES THE FORTUNE AND FATE OF ALL OTHERS. INTERDEPENDENCE, THROUGH TRADE AND THROUGH DELIBERATE COOPERATION, IS A NECESSITY IN THE ENERGY FIELD. IT CARRIES A RISK OF VULNERABILITY, BUT IT CAN ALSO BENEFIT ALL WHO PARTICIPATE.

## SUSTAINED ATTENTION.

IT IS BOTH CORRECT AND USEFUL TO SPEAK OF THE ENERGY PROBLEM, NOT THE ENERGY CRISIS. WHILE A CRISIS CAN OFTEN OCCUR -- A TEMPORARY SHUTDOWN, A DISRUPTION, AN ACCIDENT -- THIS IS NOT THE ESSENCE OF OUR ENERGY CONCERNS. INSTEAD, WE ARE DEALING WITH A SET OF ISSUES THAT CAN NO MORE BE SOLVED THAN OTHER COMPLEX ISSUES OF SOCIETY SUCH AS WORLD HUNGER. WHAT WE HAVE IS NOT AN EVENT BUT A PROCESS THAT CONTINUES OVER TIME. THAT MAKES IT HARD; A PROCESS NEEDS SUSTAINED ATTENTION. IT LACKS THE KIND OF EXCITEMENT AND THE GRATIFICATION BROUGHT BY "VICTORY" OVER ADVERSITY, AS CAN OCCUR IN A CRISIS. EFFECTIVE ENERGY ACTIONS TEND NOT TO BE DRAMATIC, AND THEIR EFFECT IS OFTEN NOT EASILY DETERMINED OR EVEN VISIBLE. MOREOVER, WHEN THE PRESSURE EASES, THERE IS A TENDANCY TO TURN TO OTHER THINGS. THUS, INSISTENCE ON SUSTAINED ATTENTION IS CRITICAL.

BECAUSE ENERGY IS SO PERVASIVE AND SO STRONGLY LINKED TO ECONOMIC PERFORMANCE, THERE ARE OF NECESSITY MANY ACTORS. SOME BELIEVE THAT IT IS GOVERNMENT'S ROLE TO MANAGE ENERGY MATTERS; OTHERS ASSIGN THAT ROLE LARGELY TO MARKETS OR, MORE BROADLY, TO THE ACTIONS OF INDIVIDUALS. IN REALITY, THERE IS A ROLE FOR BOTH. IN MARKET ECONOMIES, INDIVIDUALS, OR THE PRIVATE SECTOR, EXERCISE CHOICES -- IN THE AMOUNT AND KIND OF ENERGY USED. GOVERNMENT SETS THE FRAMEWORK IN WHICH THESE CHOICES TAKE PLACE. OF EQUAL IMPORTANCE, IT PERFORMS THOSE FUNCTIONS THAT ARE DICTATED BY THE BROAD NATIONAL INTEREST BUT THAT INDIVIDUALS ARE INCAPABLE OF UNDERTAKING. THUS, IN RESPONSE TO NATIONAL REALITIES, STRONG GOVERNMENT LEADERSHIP -- THOUGH NOT NECESSARILY OF AN INTERVENTIONIST KIND -- IS IMPORTANT IF NOT ESSENTIAL. LEADERSHIP IS EXPECTED ESPECIALLY FROM THOSE COUNTRIES THAT PLAY A LARGE ROLE AS EITHER CONSUMERS OR PRODUCERS OF ENERGY. THEIR ACTIONS AS NATIONS IMPINGE MOST HEAVILY ON THE DESTINIES OF OTHERS.

OPTIONS AND FUTURES.

THE ENERGY OPTIONS DIFFER FOR DIFFERENT COUNTRIES AT DIFFERENT TIMES. ONE THING THEY ALL HAVE IN COMMON IS AN INEVITABLE TRANSITION TO SUSTAINABLE ENERGY TECHNOLOGIES.

o FOR THE CURRENTLY MOST INDUSTRIALIZED COUNTRIES, THE PRINCIPAL OPTIONS ARE:

oo FOR THE NEXT 20-30 YEARS:

- CONTINUED USE OF OIL, BUT AT A DECREASING RATE
- CONTINUED USE OF GAS, DETERMINED BY COST AND AVAILABILITY
- SELECTIVELY INCREASED USE OF COAL, WITH INCREASING ATTENTION TO ITS ENVIRONMENTAL AND OTHER PROBLEMS
- DEVELOPMENT OF NUCLEAR POWER, AS SAFELY AS POSSIBLE, WITH TECHNOLOGIES THAT ARE PROLIFERATION-RESISTANT
- SELECTIVE DEVELOPMENT OF HYDROPOWER AND OTHER RENEWABLE RESOURCES, PARTICULARLY SOLAR ENERGY
- ATTENTION TO INCREASED EFFICIENCY OF USE, FOR WHICH MANY OPPORTUNITIES EXIST

THIS LAST ITEM IS ESPECIALLY IMPORTANT, BECAUSE

1) INDUSTRIALIZED COUNTRIES USE THE BULK OF THE WORLD'S ENERGY, AND THEREFORE INCREASING ENERGY PRODUCTIVITY HAS GLOBAL BENEFITS.
2) IT EASES THE TRANSITION TO SUSTAINABLE SOURCES BY BUYING TIME.
3) IT DISPLACES THE COSTLIEST AND LEAST ATTRACTIVE SOURCES, BOTH NOW AND LATER.

oo FOR LATER:

- COMPLETION OF A TRANSITION ALREADY STARTED, TO SUBSTANTIALLY DECREASED USE OF FOSSIL FUELS, AND TO INCREASED USE OF RENEWABLE OR VIRTUALLY INEXHAUSTABLE ENERGY SOURCES. THERE ARE ONLY TWO MAJOR ONES: SOLAR POWER IN VARIOUS FORMS, AND NUCLEAR POWER IN VARIOUS FORMS. IF THE TIMETABLE SHORTENS, SO MUCH THE BETTER.
- CONTINUED IMPROVEMENT OF ENERGY PRODUCTIVITY.

o For the currently less industrialized countries, the principal options are:

oo For the next 20-30 years:

- Continued use of oil, gas, and other fossil fuels as governed by economic circumstances
- Increased development of domestic fossil fuels via independent or cooperative international programs
- Adoption of nuclear power at an appropriate scale, in countries in which the requisite infrastructure clearly exists
- Improvement of use and supply of biomass in environmentally sound ways, with special attention to the deforestation problem
- Development of hydropower, large and small, and other renewable resources, particularly solar energy
- Improved efficiency of use

oo For later:

- The energy programs of the industrialized and currently less industrialized countries will, if all goes well, approach each other much more closely than they do at present; therefore as seen imperfectly at the current time, the same options should apply.

Every present and future option has defects or difficulties (otherwise it would have been adopted and we would have no energy

PROBLEM); THE TRANSITION PERIOD OF 20-30 YEARS, WHILE SEEMINGLY LONG, IS DECEPTIVELY SHORT FOR DEVELOPING THESE MAJOR OPTIONS ON A GLOBAL SCALE.

PROGRESS.

OVER THE PAST DECADE WE HAVE DRAMATICALLY IMPROVED OUR UNDERSTANDING OF GLOBAL ENERGY RESOURCES AND USES. THAT UNDERSTANDING NOW PROVIDES THE BASIS FOR MEETING CURRENT NEEDS, IDENTIFYING POTENTIAL LONG-TERM SOLUTIONS, AND MOVING FROM ONE TO THE OTHER. THE TRANSITION, REQUIRING DECADES, IS PRIMARILY DRIVEN BY THE CHANGING ECONOMICS OF ENERGY AND IS STRONGLY INFLUENCED BY CHANGING TECHNOLOGY. IT WAS INITIALLY TRIGGERED BY THE SUDDEN CHANGE IN OIL PRICES THAT OCCURRED IN 1974, BUT THE CONDITIONS HAD BEEN LAID LONG BEFORE. IT CONSISTS OF MOVING FROM AN OIL-DOMINATED SUPPLY SYSTEM TO A SUCCESSOR SYSTEM OF A VARIETY OF ENERGY SOURCES THAT, TAKEN AS A WHOLE, ARE MORE RESILIENT AND WILL LAST LONGER. IT ALSO CONSISTS OF A SHIFT TO SUBSTANTIALLY HIGHER ENERGY PRODUCTIVITY -- THAT IS, WRINGING MORE OUT OF EACH UNIT OF ENERGY.

AS EACH NATION PROGRESSES IN THIS TRANSITION, ITS SUCCESS OR LACK OF SUCCESS REFLECTS UPON OTHER NATIONS. THIS FACT OF INTERDEPENDENCE CARRIES SPECIAL WEIGHT IN THE CASE OF THE LARGEST ENERGY CONSUMERS. FOR EXAMPLE, SMALL GAINS IN PRODUCTIVITY FOR THEM CAN MEAN LARGE DIFFERENCES IN ENERGY AVAILABLE TO OTHERS.

Much progress is already evident, even though the transition is less than a decade old. Supplies are being developed, and many former users of oil are shifting to other fuels. Very impressive gains in energy productivity have been achieved in many countries, and much more is possible. Unfortunately, the progress is mixed. Some countries are doing much better than others. Those that have been forced to be especially energy-conserving and have developed actions and policies to that purpose have made the most progress. Whether the rate of progress can be maintained and accelerated (or finally begun in some cases) will determine the shape and magnitude of the problem we will face in the future.

## B. CONCLUSIONS AND RECOMMENDATIONS

### Assessments.

Each nation rightly deals with its unique energy situation in the way it deems best. There is no perfect, universally applicable energy technology strategy. Each country must seek its own mix of energy supplies and uses, and this mix will change over time. An appropriate mix will provide resilience to accommodate change and uncertainty, and to protect against contingencies. Therefore, each nation should carefully assess its energy options on a continual basis and develop its strategy with due consideration for its unique opportunities and constraints (e.g., environmental, technological, economic, resource, social). In this assessment, cooperation among nations can help through technical assistance, exchange of information and methods of analysis, education and training, and cooperative research. Efforts should be made to remove barriers to free the flow of information and technology.

As stated before, actions by one nation may affect other nations, because of the way energy is used and because of the influence of these actions on world energy markets. Thus, each nation should be sensitive to the consequences of its actions on others, and there should be a broadening of international opportunities to measure and compare the progress of national energy strategies, to assess how equitably the world's total energy burden is being borne.

## Advice and Assistance.

The world's less developed countries face numerous difficulties as they seek to raise the quality of life for their people. Many of their problems, including population growth, lack of investment capital and export markets, and deforestation, are linked with and exacerbate their energy problems. While each country should look primarily to its own resources, the least fortunate countries merit special help from others who are well endowed in technology or other resources. This help could take the form of technical assistance as well as financial and material aid. Such assistance could give critically needed near-term relief. It could enable developing countries to use less energy as their economies develop than was feasible in the formative stages of the now-industrialized nations. One example of such assistance could be to establish and support pilot village-level energy systems in poor rural areas, using local fuel resources with high efficiency, with the aim of providing production inputs such as irrigation water and basic amenities such as illumination, refrigeration, communications, and water supply.

### New and Improved Options.

All available energy production and productivity options may be needed and used, but in different measures by nations according to their circumstances. For the next several decades the major supply burden will be borne by the sources mentioned earlier. But given the inertia of energy systems, it is imperative to develop and evaluate new options to assist the transition in the fuel mix and in end-use technologies. The menu of potential future options is extensive, but three technology areas, at least, can benefit from cooperative efforts -- efficiency improvement, nuclear, and solar. In each there are significant opportunities and also significant difficulties to overcome. Efforts should be made to use existing international organizations as well as bilateral and multi-lateral arrangements

TO PURSUE DEVELOPMENT AND EVALUATION OF NEW AND EXISTING OPTIONS. TWO EXAMPLES ILLUSTRATE WHAT WE MEAN:

A) RAPID DEVELOPMENTS IN ECOLOGICAL SCIENCES AND BIOTECHNOLOGY (INCLUDING, FOR EXAMPLE, GENETIC ENGINEERING) PROVIDE CAUSE FOR OPTIMISM ABOUT ADVANCES IN HOW WE USE THE SUN. DIFFERENT NATIONS HAVE DIFFERENT THINGS TO CONTRIBUTE TO A COOPERATIVE EFFORT, INCLUDING PLANT MATERIALS (E.G., SEEDS) AS WELL AS TECHNICAL EXPERTISE.

B) CONCERN ABOUT NUCLEAR WEAPONS PROLIFERATION STANDS IN THE WAY OF THE UNIVERSAL AVAILABILITY OF NUCLEAR POWER. IF THE TWO COULD BE UNAMBIGUOUSLY SEPARATED, MANY OF NUCLEAR POWER'S OTHER PROBLEMS (SUCH AS SAFETY, AND WASTE MANAGEMENT) COULD BE MORE EASILY ADDRESSED IN A COOPERATIVE SPIRIT.

CONTINUATION.

THE SPIRIT OF THESE INTERNATIONAL ENERGY SYMPOSIA SHOULD BE CONTINUED THROUGH MEETINGS CONVENING BI-ANNUALLY IN KNOXVILLE TO EVALUATE SUCCESSES AND FAILURES IN MANAGING THE WORLD ENERGY PROBLEM. SUCH A SERIES WOULD ENCOURAGE FURTHER DISPASSIONATE, CAREFUL THINKING, AND WOULD BE A PERMANENT MEMORIAL TO THE EFFORTS OF THE 1982 WORLD'S FAIR TO PROMOTE INTERNATIONAL UNDERSTANDING AND COOPERATION. THE FIRST MEETING OF THIS CONTINUED SERIES, HELD IN 1984, SHOULD BE DEVOTED TO THE TOPIC, "MANAGING THE ENERGY TRANSITION."

* * * *

PARTICIPANTS FROM MANY NATIONS, REFLECTING AN EXTRAORDINARY DIVERSITY OF ECONOMIC STATUS, RESOURCE AVAILABILITY, TECHNOLOGICAL SOPHISTICATION, AND POLITICAL SYSTEMS, HAVE CONTRIBUTED TO THESE SYMPOSIA. THE COMMONALITY OF VIEWS ON ENERGY ISSUES HAS BEEN REMARKABLE. ALTHOUGH NATIONAL PROBLEMS DIFFER, THE FUNDAMENTAL CHALLENGE IS STRONGLY SHARED -- SO STRONGLY THAT MORE INTENSIVE INTERNATIONAL COOPERATION AND THE CONTINUATION OF INTERACTIONS SUCH AS THESE SYMPOSIA ARE IMPERATIVE IF THE NATIONS OF THE WORLD ARE TO ACHIEVE A GOAL OF A JUST AND SUSTAINABLE ENERGY FUTURE.

Mr. HEITOWIT. Thank you, Mr. Beach, and thank you, Dr. Lambert, for welcoming us here to your fine fair in Knoxville, Tenn. We appreciate all your help in arranging this event for the Committee on Science and Technology.

My name is Ezra Heitowit. I am with the staff of the Committee on Science and Technology, and with me today are my staff colleagues. Starting on my left, Dr. Harold Hanson, who is our executive staff director; Dan Steinway, representing the minority for the Committee on Science and Technology, Dr. Gene Frankel on my immediate left, who is the expert in conservation and renewable energy on the staff.

To my immediate right, Dr. Jack Dugan, who is the staff director of the Subcommittee on Energy, Research, and Production, which is chaired by Congresswoman Marilyn Bouquard from Tennessee. All the way on the right is Wanda Marinelli, who is also on the staff and is giving us assistance on this event.

Let me first apologize on behalf of the committee. We had expected to have a full-fledged hearing this morning with Members of the U.S. House of Representatives. Unfortunately they were in session late last night, as many of you may know, debating the first budget resolution. There were a number of very, very important votes on this piece of legislation, and, unfortunately, this obliged the Members to cancel their plans to come to Knoxville. Our chairman, the Honorable Don Fuqua, the chairman of the Committee on Science and Technology, directed the staff to go ahead with this function and hold it as a symposium on renewable energy in the 1980's.

The chairman believes that the testimony we receive today is of extreme importance to the committee and the U.S. Congress in our consideration of energy research.

Dr. Hanson will now present a statement for the Honorable Don Fuqua, chairman of the Science Committee.

Dr. Hanson.

Mr. HANSON. I wish to express for Mr. Fuqua his regrets that he could not be here this morning. I want to put into the record the statement that he would have made if he were here.

[The information follows:]

# Opening Statement
# of the
# HONORABLE DON FUQUA (D-FLA.)
# Subcommittee on Energy Development and Applications
# Hearing on
# Renewable Energy for the Eighties

Knoxville, Tennessee
May 28, 1982

It is a pleasure to welcome my colleagues from the Subcommittee, the Tennessee delegation, our witnesses, officials of the World's Fair, and guests, to this, the first ever Energy Development and Applications Subcommittee hearing at a world's fair. I hope the hearing will be as stimulating as its surroundings.

It is time to affirm our national commitment to renewable energy.

In the mid 1970's Americans were captured by the

DREAM OF TURNING THE ENORMOUS RESOURCES OF SUNLIGHT, WIND, BIOMASS, GEOTHERMAL AND OCEAN THERMAL GRADIENTS LAVISHED UPON US BY NATURE INTO USEFUL ENERGY FOR MANKIND.

RESPONDING TO THAT DREAM THE SCIENCE COMMITTEE INITIATED AND PASSED THROUGH CONGRESS A SET OF LANDMARK LAWS. THE GOAL OF THIS LEGISLATION WAS TO USE THE RESOURCES OF THE FEDERAL GOVERNMENT, WORKING COOPERATIVELY WITH AMERICAN INDUSTRY, TO TURN THE DREAM OF RENEWABLE ENERGY INTO REALITY.

NOW WE ARE BEING TOLD THAT THE DREAM WAS AN UNNECESSARY INTRUSION OF THE FEDERAL GOVERNMENT INTO THE WORKINGS OF THE FREE MARKET. THE FEDERAL BUDGET FOR RENEWABLE ENERGY HAS BEEN CUT BY 87 PERCENT; THE TAX CREDITS PASSED BY CONGRESS FOR RENEWABLE ENERGY SYSTEMS IN 1978 AND 1980 ARE BEING THREATENED.

All this has happened at a time when opinion polls consistently show that Americans continue to believe in the dream of renewable energy, that sunlight and wind and biomass are the preferred fuels for the future of an overwhelming majority of U.S. citizens.

It is time, therefore, to revitalize and affirm our national commitment to renewable energy. We applaud and welcome the efforts of the private sector in this field, especially the recent announcements of large solar and wind projects. But we also recognize that the benefits of renewable technologies are national in scope, and the problems involved in their development transcend the resources of any single firm. A strong federal leadership role is essential to sustain progress in this field.

It is appropriate that we begin our hearings on "Renewable Energy for the Eighties" at the Knoxville World's Fair. This Fair is itself the realization of a dream -- a dream that many thought was impossible or impractical. Yet, through the sustained efforts of local citizens working with their city government -- and the able assistance of my colleagues, Mrs. Bouquard and Mr. Duncan -- that dream has come true and has surpassed all expectations for its success. Let us hope we will be able to say the same of the renewable energy dream by the end of this decade.

We have with us as witnesses today a group of distinguished researchers from the Southeast who have worked hard to bring the dream of renewable energy to fruition. We have asked them to share with us their expertise in this field.

Mr. HANSON. It is time to reaffirm our national commitment to renewable energy. In the mid-1970's, Americans were captured by the dream of turning the enormous renewable resources of the Earth—sunlight, wind, biomass, geothermal and ocean thermal gradients into useful energy for mankind.

Responding to that dream, the Science Committee initiated and passed through Congress a set of landmark laws. The goal of this legislation was to use the resources of the Federal Government, working cooperatively with American industry, to turn the dream of renewable energy into reality.

The question is being raised these days as to whether now that dream was an unnecessary intrusion of the Federal Government into the workings of the free market. The Federal budget for renewable energy has been cut by 87 percent. The tax credits passed by Congress for renewable energy systems in 1978 and 1980 are being threatened.

All this has happened at a time when opinion polls consistently show that Americans continue to believe in the dream of renewable energy, that sunlight and wind and biomass are the preferred fuels for the future of an overwhelming number of the U.S. citizens.

It is time therefore to revitalize and reaffirm our national commitment to renewable energy. We applaud and welcome the efforts of the private sector in this field, especially the recent announcements of large solar and wind projects. But we also recognize that the benefits of renewable technologies are national in scope and the problems involved in their development transcend the resources of any single establishment.

A strong Federal leadership role is essential to sustained progress in this field.

It is appropriate that we begin our hearings on renewable energy in the 1980's at the Knoxville World's Fair. This fair is, itself, the realization of a dream, a dream that many thought was impossible or impractical.

Yet, through the sustained efforts of local citizens working with their city government and the able assistance of congressional representatives from this area, Mrs. Bouquard and Mr. Duncan, that dream has come true and has surpassed all expectations for success.

Let us hope that we will be able to say the same of the renewable energy dream by the end of this decade. Thank you.

Mr. HEITOWIT. And now, Dr. Jack Dugan will make a presentation on behalf of Chairwoman Bouquard.

Mr. DUGAN. Thank you, Ezra.

Mrs. Bouquard also regrets not being here today and is particularly sad in the sense that she was so instrumental in planning for the fair and actively involved in supporting funding for the fair in Congress.

The message she gave to me yesterday when it was apparent she would not be able to appear, the message she wants to deliver here, is that she feels that it is still very important to have a balanced energy program.

Mrs. Bouquard noted as early as when the fiscal year 1982 request came to Congress from this administration that there were serious problems in the lack of a balanced energy research and development approach. She saw, prophetically, 15 months ago, that this would lead to a fight in Congress between the advocates of solar and conservation versus possibly the fossil fuel people, but certainly the nuclear supporters, over where the appropriated funds would go.

She felt that controversy would be inevitable and it has come to pass. Tragically, as we go through the fiscal year 1983 budget process, we are still having great discomfort from that type of conflict Congress. The latest budget proposal which Mrs. Bouquard spoke strongly against the other day, the Latta budget amendment, was even worse in terms of a balanced energy program that the Reagan fiscal year 1983 submission.

Mrs. Bouquard has worked hard with the chairman of our committee, Mr. Fuqua, the leadership of the Budget Committee, and the leadership of the House, to see that energy was treated in a balanced manner in the fiscal year 1983 budget proposals.

Unfortunately, now, we do not have any budget proposal adopted, but I think what she has said in terms of the difficulties caused by underfunding energy will hopefully have some positive influence on the proposals we see when the Congress reconvenes.

She has strongly supported significant add-ons in solar, conservation, geothermal and fossil energy to redress the imbalance in the request, and she was hopeful that her add-on recommendations would be a minimum level of funding for fiscal year 1983 and hopefully that the fiscal year 1982 levels would prevail in funding the renewable energy areas.

Finally, I think that today she is looking forward to getting some advice from the witnesses on the direction of the renewable energy program in fiscal year 1983 and beyond, and I take that very seriously in terms of recommendations on the budget, in this Congress and beyond.

Thank you.

Mr. HEITOWIT. We would like now to start the symposium on the subject of renewable energy in the 1980s, needs for further research, development and demonstration. We will have the witnesses come forward in a panel format.

The first panel is Dr. David L. Block, director of the Florida Solar Energy Center; Dr. Edward Lumsdaine, director of the Energy and Environmental Research Center here at the University of Tennessee; and Dr. Jon Veigel, director of the North Carolina Alternative Energy Corp. in Research Triangle Park, N.C.

We welcome you gentlemen and propose to have you each make your oral presentations and then engage in a dialogue of questions and answers following your statements.

We will take your statements in their entirety for the record, and you are free to summarize as you wish.

Dr. Block, will you begin, please.

## STATEMENTS OF DAVID L. BLOCK, DIRECTOR, FLORIDA SOLAR ENERGY CENTER; EDWARD LUMSDAINE, DIRECTOR, ENERGY AND ENVORNMENTAL RESEARCH CENTER, UNIVERSITY OF TENNESSEE; AND JON VEIGEL, DIRECTOR, NORTH CAROLINA ALTERNATIVE ENERGY CORP.

Dr. **Block.** Thank you, Ezra.

Thank you and the staff members of the subcommittee for inviting me to express my views on needs for renewable energy in the 1980's. I have to admit that many of my views will reiterate the two statements just made.

I planned to present a synopsis from my written testimony. My views are predicated in large part on my experience as director of the Florida Solar Energy Center, and based on my experience as project director of a DOE-funded solar technology assessment project.

Two other participants in that assessment are also here today, Dr. Ed Lumsdaine and Dr. Jerry Birchfield.

Using the Florida Solar Energy Center and the assessment project as a base, let me present a view of solar energy in the 1980s by first examining our strengths and accomplishments.

In the utility sector, companies have demonstrated an increasing interest in solar. This interest has been piqued by photovoltaics, the Barstow Power Tower project, the Shenandoah Total Energy project, several wind development programs, OTEC and solar hot water incentive programs. Florida utilities have been especially interested in photovoltaics, OTEC and solar hot water incentives.

In the private sector, homeowners are pleased with solar. They are seeing significant improvement in the performance of solar water heating systems, coupled with moderate increases in system costs. They are also pleasantly affected by the many passive solar options which have been incorporated into thousands of new homes. Solar water heating and passive are especially important to the homeowner because they immediately impact the pocketbook.

The biomass sector has shown some encouraging growth through the development of privately funded alcohol fuel facilities and in an increased use of wood for process heat.

The solar industry itself has gradually stabilized although it is still not what would be classed as a strong industry. Present predictions are for an increase in sales to over $1 billion per year.

However, this seemingly sunny picture of solar energy is being clouded by some disturbing trends.

Recently, several large, important companies have de-emphasized or discontinued their solar-related activities: PPG and Exxon have stopped manufacturing solar collectors; Olin Brass no longer manufactures solar absorber plates; Westinghouse has chosen not to continue its OTEC work.

The DOE decision to de-emphasize solar is also disturbing. This decision has the potential to bring the present level of research to a halt and to create a 5- to 10-year void in solar technology development. The threat of repeal of Federal energy tax credits mentioned by Dr. Hanson frightens the solar industry and disturbs those of us working to move solar into the marketplace.

In my interaction with the Florida manufacturers, the most frequently mentioned item is the threat of the Federal tax credit repeal.

We must consider both the positive and negative trends in solar within the broader context of our energy policy as a whole. Current policy may be comforting from an inflationary point of view; however, it does not provide a stable base for long-range energy supplies and national security.

To follow a policy which places all our trust in a single, finite resource—nuclear—ignores the hard lessons we have so recently learned. It sets up the public and the marketplace for another series of economic and social shocks. I cannot stress strongly enough the importance and urgency of developing a broad-based and balanced energy program. I believe the energy policy of the State of Florida is a good example of that kind of program.

I also would like to mention I do not believe there needs to be a conflict between any of the energy programs. Solar construction, and nuclear must all be pursued. The program must be balanced.

Assuming the decision is made for just such a broad-based program on the Federal level, this committee must then address DOE funding, its perception of R&D, and its administration of congressional programs.

First speaking to the funding. The 1981 budget for solar, $580 million, represented an aggressive program. The 1982 budget—$275 million—was skeletal, simply a bare-bones maintenance program. The administration proposal for 1983—$73 million—can be considered funeral expenses. It is a budget I must strongly oppose. By providing a minimal budget of $275 million for solar, solar activities can be maintained. When the crunch comes—and it will—those activities can be easily accelerated to a productive level.

The definition of R&D. One reason for the decision to phase out solar funding is based, at least in part, on a narrow and short-sighted view of R&D activities. DOE seems to perceive R&D to be theoretical laboratory experimentation, university professors in pristine white coats.

Solar R&D is, however, applied R&D that surveys the solar technologies of greatest potential, determines what information is missing, answers those questions, and provides the information to the market.

Of course, there are some solar technologies that still require fundamental research. An example is developing new chemical combinations for more efficient photovoltaic cells. Yet applied R&D is still needed for those solar technologies which have been in the marketplace for years. An example is the need to determine solar domestic hot water system efficiency in various U.S. locations. Solar domestic hot water systems have been sold for many years. They are very much in the marketplace and yet there is very urgent need to determine system efficiency and performance for various U.S. locations. This example is what I consider to be a strong R&D project.

Administration of the energy program. Another severe problem with the Federal energy program is its unstable nature. The solar portion of DOE is in shambles because of the yo-yo effect of its budget and the elimination and abdication of virtually all productive personnel. This is not only extremely inefficient, but it is also imposing a 5-year gap in technology. The program must be stabilized in order to prevent even greater losses in efficiency and technology.

With these points in mind, let me offer a set of priorities for the solar portion of the national energy program.

Priority one programs are those in which the process of development promises enormous benefit, but which need continued R&D support to achieve broader application and industrial growth. They include:

Photovoltaics, the most promising of the active solar technologies. PV is simple, has no moving parts, can produce significant amounts of electricity, and has the potential for widespread application. Government support of PV R&D must continue in order to develop practical applications and to achieve the price goal.

Passive heating and cooling is far-advanced, cost-effective, and has the potential to reduce conventional building energy use by as much as 80 percent. The building industry is too fragmented and financially distressed to fund and organize its own research programs, so Government programs must continue.

Biomass and alcohol fuels can annually contribute 8 to 10 quads of energy by the year 2000—thus, their importance. R&D is still needed in process technology and tradeoff studies. The Federal Government is the only entity which can support this advanced and sometimes costly research.

Priority II programs are those solar technologies closer to market feasibility and those which do not appear as yet to have as high a potential. They include:

Water and space heating systems which are technically well-developed and well-accepted in the marketplace. Work must continue to strengthen the industry by developing standards and performance evaluations.

OTEC has been shown to be feasible but developmental research is still required to achieve commercial viability. Pilot plants must be constructed to prove that viability to industry.

Wind system technology is well advanced, but large-scale systems cannot be evaluated for use by utilities until performance, maintenance, and operation experience is obtained.

Solar thermal central receiving technology is in the intermediate stage of development. Given a reduction in heliostat costs, studies predict SCTR can be economically competitive with conventional energy sources. Consequently, projects such as those at Shenandoah and Barstow must be operated to determine the commercial viability of the concept.

Priority III programs are those which present large economic hurdles, but which nevertheless are important applications. They include:

Industrial process heat. Although Federal demonstrations have shown some problems, the energy saving potential of IPH in a high energy-use sector justifies continuing R&D to overcome those problems. Federal programs must be completed and collect the pertinent data.

Active cooling by thermal processes shows little chance of becoming economically competitive but Federal and State programs should monitor present demonstrations and report on the results. Cooling by other means (photovoltaic and passive) are encouraging.

Having offered this list of priorities for solar research, I recommend the following actions:

First, reestablish a broad-based Federal energy program, encompassing all the technologies, with emphasis on resources within the United States.

Second, maintain solar funding at the 1982 fiscal year level.

Third, expand the definition of the R&D to encompass near-term technologies and activities that will lead solar to the marketplace.

Fourth, stabilize the DOE solar program in terms of manpower and funding.

Fifth, continue priority I and II solar programs.

This committee can greatly affect the country's energy future. Our Nation must develop its own energy resources and the Federal Government must take the lead in that process. Our economy and national defense depend upon it. We know that the energy crisis is not over. Our national consciousness of this critical issue has simply been diverted to other, more overtly nationalistic problems.

This hearing is being held at a World's Fair dedicated to energy. This grand exposition shows what can be done if we put our talents to work. Let's go to work.

Thank you.

[The prepared statement of David L. Block follows:]

## PREPARED STATEMENT OF DAVID L. BLOCK, DIRECTOR, FLORIDA SOLAR ENERGY CENTER

### SOLAR ENERGY TECHNOLOGY: RESEARCH AND DEVELOPMENT NEEDS

Testimony by:
David L. Block
Director
Florida Solar Energy Center
Cape Canaveral, Florida

Given to:
U.S. House of Representatives
Energy Development and Applications Subcommittee
of the
Committee on Science and Technology

May 28, 1982
Knoxville, Tennessee

I thank this Committee and its Chairman, Representative Fuqua, for an opportunity to express my views on the status and future of solar energy technology and on solar research and development priorities. My comments on the current federal energy program will be as seen from Florida, a state with an aggressive and diversified energy program.

I speak to you as director of the Florida Solar Energy Center. FSEC is one of the most active solar energy agencies in the nation, outside of those supported by the federal government.

I also speak to you as director of the U.S. Department of Energy-sponsored project which assessed the status of solar energy technology in 1981.

My involvement in these two activities forms the basis of my testimony today.

FSEC exemplifies the best results of a broad-based energy R&D policy. The Center was created in 1974 when the State Legislature recognized the impact of energy demand on the state's economy. It gave FSEC a single major imperative: to explore the state's most abundant energy source -- the sun. This legislative action has propelled Florida into a role of national leadership in the solar energy field. This leadership position has been fortified through FSEC's recognition of research needs in five critical areas: low energy building design for hot humid climates; photovoltaic applications; coordination and development of solar equipment standards, testing and certification; ocean thermal energy conversion (OTEC); and education and training of solar practitioners.

The solar technology assessment project I mentioned, completed one year ago, was DOE-funded and was intended to form the basis of federal solar energy policy. Eleven nationally recognized solar experts (none affiliated with the federal government) were commissioned to assess and report on the status and future of their particular area of expertise. This project emphasized federal government programs and their role in solar research.

The assessment included an overall project summary in which I assigned a priority to each solar energy program based on its state of technological development, economics and marketplace potential. Based on that assessment, on the success of recent solar applications, and on the Florida solar experience, let me offer a brief summary of the status of solar energy applications and their position in the marketplace.

There is heightened interest, on the part of the nation's utilities, in solar electric generation processes. Their interest has been piqued by the impacts of several solar technology projects. Among them are the Barstow Power Tower project, several wind development programs, Mini-OTEC and OTEC I, and, of course, the increase in photovoltaic cell efficiency with its concurrent price decrease.

There has been significant market penetration by solar fuels. Development facilities have been constructed for biomass and alcohol processing. Utilization of these fuels has yielded valuable information on performance expectations and capabilities.

In the private sector, homeowners have seen significant improvement in solar water heating systems. They have also been pleased with the resultant increase in system and energy cost savings. These improvements are due, in large part, to the success of collector testing and performance standards programs. Homeowners have also been pleasantly affected by increased incorporation of passive and active solar systems in the construction of thousands of new homes.

Now that we know where we are, we must establish priorities for the future of solar R&D. But first we must come to a consensus on the definition of the term "research and development." The current DOE policy seems to perceive "R&D" to be university professors in white lab coats working in a test-tube filled, pristine laboratory. While I am a professor of engineering and represent the university community, I feel solar R&D is not that kind of lab coat experimentation, isolated from the realities of the field and the marketplace. It is, instead, the kind of applied research and development that surveys the solar technologies of greatest potential, determines what information is missing to make them marketable, answers the unanswered questions, and then provides that information to the marketplace.

Solar R&D activities must, of necessity, be as diverse as are the solar technologies themselves. There are, by some counts, as many as 20 different solar technologies. These range in complexity from the very complicated -- such as photovoltaics and OTEC -- to the very simple -- such as batch solar water heaters. The state of development of each covers an equally broad range, from those already in the marketplace -- such as solar hot water systems -- to those at a level of fundamental research -- such as photovoltaic cell functioning. However, given a broader definition of research and development, even highly developed solar technologies may require R&D. For example, solar hot water systems have been in the marketplace for years, yet R&D work is still needed in order to evaluate system performance as applied to various U.S. locations.

I have been speaking only of the diversity of solar technologies. In reality, energy technologies as a whole are equally diverse. Each has potentially great benefits in appropriate applications. It is that diversity which this committee must use as a premise for delineating the nation's energy future. First, the committee must take a long-term view of the national good. Recent trends in energy policy, while comforting from an inflationary point of view, do not augur well for the continued expansion of long-range energy supplies. A slackening of our resolve to help new technologies find their niche in the marketplace can only be viewed as a significant setback to our national security and economic well-being.

Second, this committee must ensure that America has a choice of energy resources to utilize where appropriate. To follow a policy of trusting in a single, finite resource ignores those hard lessons we have so recently learned. It sets up the public and the marketplace for another series of economic and social shocks.

The wholesale abandonment of technological advancements in fossil, geothermal, solar and conservation areas cannot serve this nation's interests. And yet, looking back on the past year, one sees just such a disturbing national trend. In the case of solar alone, our technology has not appreciably advanced and may, in fact, have lost ground. The dismantling of technology teams and threats of tax credit repeals have hurt our programs and those of the solar industry. Our activities at the Florida Solar Energy Center are increasing in an effort to fill the void. But we can meet the needs only of Florida, not of the entire nation.

Unfortunately, the American people are being made to believe that the energy crisis is over because oil is plentiful and oil prices have stabilized. There seems to be no recognition of the fact that energy has contributed greatly to the chaos of today's economy. Energy is one of the major factors affecting our economic development. Cheap energy in the early seventies, with oil at $1.50 per barrel, gave rise to a national GNP growth of over five percent. Today, with oil costing $32 per barrel, a 2100 percent increase, the GNP growth is at 2½ percent, a 100 percent decrease. Quoting from an article in the March 1982 issue of Forbes Magazine. "According to Bankers Trust, it now takes twice as much capital to develop the same volume of energy as it did a decade ago. You have to dig deeper, look harder and spend more money. In economic terms, the marginal efficiency of the extra capital involved is very, very low. The drain on the U.S. economy -- and that of the world -- has been devastating. Whether you put the primary blame on oil prices, inflation or interest rates, they're part of the same complex of problems."

I have been stressing the importance and urgency of developing a broad-based and balanced program for energy research and development. With that in mind, let me now address national solar energy R&D priorities.

Priority One Programs are those which are in the process of development and which promise enormous benefits to the nation but which need continuing R&D support to achieve broader application. They include:

Photovoltaics which is the most promising of the active solar technologies because of its simplicity (lack of moving parts), its ability to impact electrical energy generation, and its potential for widespread application -- from individual homes to central utility power plants. Governmental support for PV programs must continue. It is imperative in achieving PV price goals. Work is also required in the development of practical applications. Achievement of the price goal is still the major priority and must not be abandoned. This is an example of the highest level of R&D needed.

Passive Heating and Cooling is a far-advanced and cost-effective solar technology. Federal support of this program must continue because passive has the potential to reduce conventional building energy use by up to 80 percent. However, to achieve its greatest benefits, programs must be developed to educate the building industry, to develop passive cooling techniques, and to combine passive techniques with conservation. Federal R&D in this area is, again, of the highest priority. Federal research into building energy use must continue since the building industry is too fragmented to fund and organize its own research.

Biomass and alcohol fuels are extremely important because they have the ability to contribute 8-10 quads of energy per year by the year 2000.

Their importance is heightened by their potential as a liquid fuel. Processes for utilizing biomass are known and understood; however, optimization of process technology and tradeoff studies are still required. The federal government is the only entity which can support this advanced and sometimes costly research.

Priority Two Programs are those technologies which are closer to the marketplace or those which do not appear, at this time, to have as high a potential. However, they deserve continued R&D support to develop effective applications. They include:

Water and Space Heating systems which are technically well-developed and well-accepted in the commercial marketplace. Economic analyses of their impact are favorable. However, work must continue to develop standards and performance evaluation. Programs in the market sector must be supported in order to strengthen the solar industry and the incorporation of solar by the building industry. These programs need to be closely coordinated with those on the state and local levels.

OTEC technology has been shown to be feasible, but developmental research is required on both open- and closed-cycle systems before commercial viability is achieved. Studies have predicted OTEC to be cost-competitive with conventional energy generation. However, pilot plants of a size scaled to commercial application must be constructed to prove OTEC viability. Industry will not construct OTEC plants until reliable operating and maintenance costs are determined. Determining those costs is as valid a reason for an R&D project as was initial development of the concept. Federal programs must continue to support OTEC R&D and the development of pilot plants.

Wind system technology is well advanced, but large-scale systems still require R&D. They have the potential to become economically competitive when used by utilities, but cannot be evaluated until maintenance and operation experience is obtained. Large-scale system development should be completed on existing, planned and partially constructed units. It will then be possible to obtain operational data on the performance, reliability and durability of those units. The economics of small-scale systems (<100 kw) currently favor only remote applications and the technology is at a stage of development where federal support is not required.

Solar thermal central receiving (STCR) technology is in the intermediate stage of development. Studies predict STCR systems to be economically competitive with conventional energy sources, dependent upon reduction of heliostat costs. The Barstow, California, project should be operated to determine commercial viability or inviability of the concept and to obtain reliability and durability data. The R&D effort should also be directed toward utility plant repowering applications.

Priority Three Programs are those solar technologies which present rather large economic hurdles, but are applications of significant promise if the economic problems can be overcome. They include:

Industrial process heat (IPH) technology which is in an intermediate stage of development. Federal demonstrations have been shown to be problem-prone and to have high operating and maintenance costs. However, the very large energy-saving potential of IPH in a high energy-use sector justifies continuing R&D efforts to overcome those problems. Federal programs should also complete demonstrations, where appropriate, and support the collection of performance, operation and maintenance data.

Active cooling by thermal processes is a technology which is highly developed and which has been demonstrated. The process shows little chance of becoming economically competitive because of the large collector area and amount of mechanical equipment required. Cooling through photovoltaic and passive methods appears to be more promising. Federal and state programs for thermal processes should monitor present demonstrations, however, and report their results.

Market opportunities for solar products can be expected to expand significantly. The solar industry expects to exceed one billion dollars this year. This new and exciting industry must be encouraged.

To that end, I would like to make the following recommendations to this committee:

The first and second priority solar programs must be continued. To continue, they must be adequately funded. The 1981 budget for solar, $580 million, certainly represented an aggressive program. The 1982 budget of $275 million was skeletal -- simply a bare-bones maintenance program. The current budget proposal for 1983 of $73 million is a phase-out budget which we must strongly oppose. By providing a minimal budget of $275 million for solar programs, when the crunch comes -- and it will -- the solar activities can be maintained and then easily accelerated to a productive level. A $275 million budget will avoid the impending five- to ten-year technology gap that will be the ultimate consequence of a funding phase-out.

I also recommend that this Committee expand the Department of Energy definition of research and development. Taking a larger, more realistic view of solar research and development to include near-term technologies will strengthen the nation's long-term energy base -- far more so than the current short-sighted, extremely narrow view focussed almost entirely on nuclear.

Further, I suggest that the Committee seek to ensure stability in the federal energy program. The solar portion of DOE is in shambles because of personnel and budget cuts. There is a void left by the elimination and abdication of virtually all productive personnel. That loss of expertise and skill is rending a five year gap in technology -- a gap that is daily growing larger. It's my belief that only through this committee's congressional oversight can the program be stabilized to prevent even greater losses in technology.

What does the energy future hold? I believe the answer will be greatly affected by the actions of this committee. I personally started a career in solar energy because I believed in its future. I continue to believe in solar energy and believe that solving our energy problem is the key to solving many of our economic and societal problems. The most important federal programs we need to press forward are those in alternative energies -- I make the statement without reservation. Our nation must develop its own energy resources. To that end, the federal government has the ability to make crucial contributions in technological research and development. It must continue to support alternative energies -- not to supplant the natural action of the marketplace, but to stimulate it.

As a final comment, I must state that the energy crisis is not over. National consciousness of this critical issue has simply been diverted to other, more overtly nationalistic problems. Yes, we are seeing a temporary stabilization in the price of oil, but who's kidding who?

Mr. HEITOWIT. Thank you very much, Dr. Block.

We will now go on to Dr. Lumsdaine.

Mr. LUMSDAINE. It is indeed a pleasure and honor for me to give my testimony to you today. When I see Dr. Block's testimony, I feel that there is little for me to say. I would like to add my support to what he said.

My background and qualifications for speaking on the issues before you today are given in my written testimony. Having spent the last 4 days as a participant in an international energy conference, I want to begin with a few comments before I highlight some of the key points that I have presented in my written testimony.

Now, although my testimony will be very critical of the present administration's policies on alternative energy R&D, I would like to add for the record that I am an extremely proud American, having served my country in the U.S. Air Force and with my strong support, my oldest son is now an upper classman at the U.S. Air Force Academy.

The Third World Energy Symposium just concluded yesterday here in Knoxville, with Secretary of Energy James Edwards giving the closing remarks. After 2 years of debate in three symposia by representatives from 36 nations, the final day's round of debates sounded like those of the opening session in 1980.

However, the presentation of papers by ministers and representatives of ministers from several countries was most interesting.

A common denominator was that governments strongly support conservation, and that these efforts are working. The gross national product of these countries has risen substantially since 1970. In Germany, for example, the GNP rose 18 percent, while energy consumption dropped by 2 percent. Also, most nations (developed as well as developing) strongly support renewable research and development.

France, for example, a strong proponent of nuclear power, has substantially increased its R&D budget for renewables. The Philippines are aggressively moving in the renewables field with a national commitment that many developed countries would do well to emulate.

Almost all countries are moving to diversify their energy base and stress the importance of consistent policy. In contrast, any student of energy that heard the Secretary talk yesterday, will be extremely confused by what he said with, in certain cases, seemingly contradictory statements. It is commendable to allow the market to determine energy prices without subsidies, but the Government should move in the same direction as the market forces, not against them.

One example is passive solar where government continues its general neglect, ignorance and even detrimental actions in the direction opposite to the market. It is unfortunate that market forces depend on some type of government intervention because especially in the area of conservation and renewable energy, these forces are not operating perfectly.

Government funding for renewable development, especially low tech hardware, is so necessary because private enterprise, in particular large companies, has not shown a great deal of interest in investing in this area because of the inherent nature of the product.

Low tech renewable hardware is a product that is generally relatively low cost, simple, durable. Thus in their view it has no place in our throw-away consumption-oriented society.

Energy generated by the consumer himself is seen as a threat since it is substituted for a product which can no longer be sold to him at increasingly higher prices. The profits for the industries are quite low, especially in the short term. There is little incentive to become involved in this type of development without government assistance.

Also, we must be very careful where we invest our research capital. Areas such as nuclear breeder reactors and central power solar processes require immense initial investments. The danger here is that a change in direction will be practically impossible later, even if the cost in terms of environmental damage, meagerness of output, or vulnerability to breakdowns should prove much higher than anticipated, because the cost involved will demand further assistance lest the initial investments be lost or unprofitable.

Investments in renewable R&D, on the other hand, allow changes in direction easily, depending on the process and results, because it is diversified.

It is important that goals and policies in regard to energy development be consistent, both for the near term as well as for the long term.

Little has been achieved so far for the amount of effort and money expended in solar energy research because a strong national commitment and consistent supporting action have been lacking. Unless research funding is done within the context and consistent with a strong national plan, it will not be effective.

It is apparent that if the current administration's policies are pursued, solar energy will not achieve anywhere near its potential contributions of 5 to 10 quads to the Nation's energy supply in the next 10 to 20 years. Specifically, I submit the following recommendations for renewable energy R&D.

1. Some agency designated by the President or Congress must develop a consistent and realistic energy plan which includes policy

planning as well as periodic evaluation. The emphasis must be on the most cost-effective methods for the near term.

Yet, the plan must grow out of an imaginative concept, a vision of how energy use is related to the entire fabric of our society, locally, nationally and globally. This agency should not be influenced by previous bias or ties to certain industries or be politically motivated (and I can exclude certain agencies right now).

2. Legislation must be consistent in supporting this policy at all levels of government, and conflicting signals such as subsidies for conventional energy supplies should be removed.

For instance, the present tax structure discriminates against the use of renewable energy sources which are treated as capital expenditures versus fossil fuel consumption which as operating expenses are tax deductible.

3. Federal funds must be directed toward R&D support for efficiency improvements in industry, including waste heat recovery and cogeneration.

There are thermal electric, thermal, and photovoltaic thermal cogeneration (which provides both electricity and low grade heat), and which promise to be very durable and renewable, and should receive careful attention.

Joint research ventures between government and industry and tax credits for private R&D should be encouraged. These types of activities have been very successful in Japan. R&D in biomass, especially the use of municipal waste as industrial fuel, should be encouraged in the near term. Also, because these can make a major impact in displacing the use of petroleum fuels, I am glad to see that the committee is devoting an entire day to the testimonies in the important area of biomass.

4. Since the Federal Government is the largest purchaser of nearly everything, including energy, it should have a steady and persistent program of energy conservation and renewable energy application with strict, achievable deadlines. This policy will serve to stimulate the market for renewable energy products and serve as an example for the general public.

Most military bases and government facilities that I have visited are very energy inefficient, and urgent programs with strict guidelines to improve energy efficiency and decrease waste implemented after 1973 are being eroded by the present product-oriented administration.

5. Government involvement in active solar systems such as home heating and solar industrial process heat should continue only in the areas of materials and components testing and research, and in providing some tax and other financial incentives. Most demonstrations of these solar thermal technologies have not been successful in generating private sales. They have largely been a waste of money and have in the process also damaged the image of solar energy.

Other high technology projects, such as thermal power generation or solar irrigation, have also been very expensive and have only benefited a few people.

6. The Government should consider assisting in the formulation of standards to help industry and the public to achieve confidence

in solar thermal equipment and to achieve better efficiency by quality improvement in the hardware.

7. In addition, there is one solar technology that should be vigorously supported with funding for R&D, and that is photovoltaics. It is all around you here at the World's Fair, please do see it. Especially support should be aimed at lowering cell and system costs.

Photovoltaic systems already have many cost-effective applications and an excellent future potential. If our efforts are not continued in this area, the sad experience of our automobile and television manufacturing industries being left behind by foreign competition will be repeated.

The U.S. world share of the photovoltaic market was nearly 100 percent several years ago, 80 percent last year and is expected to sharply decrease in the future.

Japan, today, has almost as many photovoltaic manufacturing plants, 10 in total, as the United States, and has one of the largest R&D efforts in this area. In addition to supporting R&D, the Government should purchase large quantities of solar cells for many remote and other cost-effective applications to stimulate the market. However, mere commercial demonstrations should not be funded; they are useless, premature and too costly.

There are many opportunities for more efficient energy use in the commercial and industrial sector where additional research should have high potential returns in the near term, such as heat recovery, district energy planning and use, cascading, cogeneration, and efficiency improvement in motors and controls. In the residential sector, the most important issues in the research areas are weatherization of existing housing stock, especially lower income, efficiency improvement in lighting and appliances, solar data collection, materials performance and tying mortgage interest subsidies to passive solar construction.

More details on these types of projects are given in my written statement.

In summary, the three areas of priority and renewable energy R&D that must receive continued, consistent and adequate funding through the 1980's are passive solar, biomass, and photovoltaics, coupled with or as part of a general program or climate of emphasis on energy conservation, or better yet, the wise use of or appropriate use of energy.

A recent SERI [Solar Energy Research Institute] study shows we can cut our present energy consumption by 20 percent in the next 20 years and be more productive at the same time. Our European partners have been doing that already.

If we just do things more efficiently, an Office of Technology Assessment study shows that we can produce between 10 to 20 percent of our energy needs by biomass alone by the year 2000 if we pursue a consistent and steady policy in support of renewable resources.

The following programs and actions should receive priority in the specific timeframe between 1982 and 1984 energy: Conservation, education about appropriate technology, support to small businesses for diversified energy R&D and to community-based projects, State energy policy planning, and development of legislative support structure on the Federal and State levels.

1985 through 1986: Continuation of strong emphasis on conservation, wide application of lower solar technologies, waste recycling, cogeneration, training of technical and semiskilled work force and attention to technology and quality hardware.

1987 to 1988: Review of progress, assistance to developing countries with domestically proven systems, reduction of Government involvement and overhead.

1989 to 1990: Emphasis may at this time shift to efficiency improvements in the transportation sector, RD&D support for many promising new projects in conservation and renewable energy, as well as in environmental protection and materials recyling.

Let me finish by quoting from a comment by Dr. David Rose of MIT. He wrote recently that a chicken can hatch its eggs in 21 days but it must have a steady policy throughout. The job not only cannot be done any quicker, but also cannot be done at all in 42 days with a policy of 1 day on and 1 day off.

Therefore, especially in times of tight budgetary constraints, it is necessary that R&D support for short-term renewable energy projects continue at an adequate level, even at the cost of having to reduce funding for long-term high technology projects. However, even more importantly, such funding must go hand in hand with a consistent supportive energy plan and a realistic national policy.

As I see it, it is decisions like these that have immense consequences for the future, even though they do not appear all that important at the time.

Thank you very much.

[The prepared statement of Edward Lumsdaine follows:]

# RENEWABLE ENERGY IN THE EIGHTIES: NEED FOR FURTHER RESEARCH, DEVELOPMENT AND DEMONSTRATION

Written Statement by

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to

Subcommittee on Energy Development and Applications
of the
Committee on Science and Technology
U.S. House of Representatives

May 28, 1982
Knoxville, Tennessee

I am delighted and grateful to have the opportunity to give my testimony to this Committee on the subject of "Renewable Energy in the Eighties: Need for Further Research, Development and Demonstration."

My background and qualifications for speaking on the issues before the Committee today include a doctorate in Mechanical Engineering and 16 years of experience working in the field of energy and environmental problems at several Universities. My first involvement in solar energy was nearly 20 years ago as a graduate student at New Mexico State University. Presently, I am the Director of the Energy, Environment, and Resources Center here at the University of Tennessee; before that I was the Director of the New Mexico Solar Energy Institute. I have worked as a consultant with a number of small and large industries, and I have been involved in solar research projects here as well as overseas. My wife and I have built and lived in passive solar houses for the past five years, houses that she has designed. One characteristic of our passive homes in

New Mexico and here in Knoxville is that there is no conventional backup heating or cooling system except for a wood-burning stove in one house and a fireplace in the other. Typical energy consumption figures for these houses are at about 25 percent of the consumption of a house of similar size in the same climatic zone, with a level of comfort equal to and in some respects better than that of a conventional house, especially in terms of quietness, ease of operation, reliability, and control options. The payback for these passive systems is generally between four to eight years.

I was one of the eleven people that participated in the Department of Energy sponsored solar energy assessment headed up by Dr. David Block of the Florida Solar Energy Center; my subject was solar industrial process heat. At the time of the this study, I had been involved with one specific solar industrial process heat project, that at the Southern Union Refinery in Hobbs, New Mexico. To prepare the assessment, I visited almost all federally funded solar industrial process heat demonstration sites (interviewing the plant managers) and was appalled at what I found. Most of the systems were not operating well; some had never worked, some had extensive damage due to faulty equipment, faulty installations, faulty maintenance; some were not being operated because O & M costs were much higher than the value of the energy received; the yield of energy useful to the industrial process was often minimal because of design errors; and user interest under these circumstances was (not surprisingly) very low. Most users were willing to consider any other options, even partial shut-down of the plants, to installing more solar equipment at company expense in case of fuel shortages. This was the end-result of a federal demonstration program which cost over $100 million and did not even yield much reliable data because of faulty data loggers; few people have benefited from the program, and the cause of solar energy, because of these examples, has received a bad name, especially in industrial management circles. What was interesting is that in one application (a fruit drying plant in California) a heat recovery wheel was later installed to improve efficiency in the operation, and this wheel, at one/tenth of the cost of the solar system, saves twice as much energy.[1]

Present government policy is still towards favoring high-technology, high-cost energy development, with the present Administration wanting to axe all support for research and development in near-term, cost-effective renewable energy projects. Granted that the nation's energy problems will be solved primarily by the American people themselves, not by the Government, and granted that the federal government's role is to establish sound public policies based on economic and social principles to encourage efficient and appropriate energy use as stated in the National Energy Plan III, then with these premises, it should not be the Government's role to select and promote favored energy sources. Therefore, all direct and indirect support and subsidies towards the production of uranium (including nuclear waste disposal), oil, gas, and coal production, synfuel development, high-technology central solar systems, etc., should cease. As long as the Government is involved in public spending for long lead-time, high-technology, high-cost development, it is favoring and directing resources to areas that may not be giving a high or even a reasonable rate of return, at the same time diverting capital resources and attention away from other, more cost-effective, more beneficial means of achieving an adequate supply of energy and a good standard of living for the present as well as future generations.

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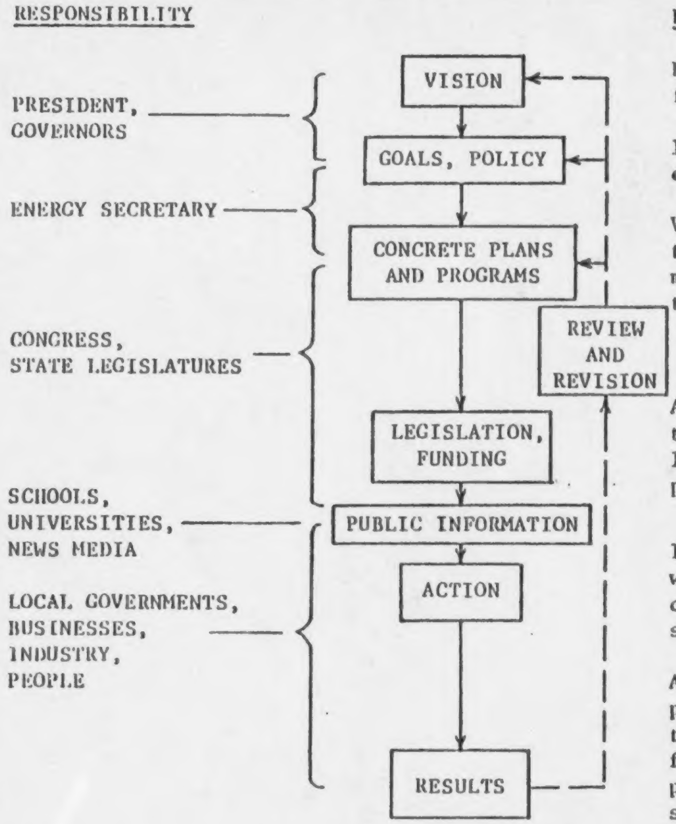
[1] Proceedings of the Solar Technology Assessment Conference, January 29-30, 1981, Orlando, Florida, sponsored by the Florida Solar Energy Center and the U.S. Department of Energy, Chapter IV, "Solar Industrial Process Heat".

Setting consistent goals and policies, both for the near term as well as the long range, is so very important; little has been achieved so far for the amount of effort and money expended because a strong national goal and consistent supporting action have been lacking. The attached figure shows an example of a strongly-defined, goal oriented plan; many alternate routes are of course possible, but unless research funding is done within the context and consistent with a strong national plan, it will not be effective. It is apparent that if the current administration's policies are pursued, solar energy will not achieve anywhere near its potential contributions of 5 to 10 Quads to the nation's energy supply in the next 10 or 20 years.

Specifically, I submit the following recommendations for renewable energy R, D, and D:

1. Some agency designated by the President or the Congress must develop a consistent but realistic energy plan which includes policy planning as well as periodic evaluation. The emphasis must be on the most cost-effective methods for the near term, yet the plan must grow out of an imaginative concept or vision of how energy use is related to the entire fabric of society, locally, nationally, and globally. This agency should not be influenced by previous bias or ties to certain energy industries or be politically motivated (this would exclude DOE).

2. Legislation must be consistent in supporting this policy at all levels of government, and conflicting signals (i.e., subsidies for conventional energy supplies) should be removed. For instance, the present tax structure discriminates against the use of renewable energy sources (which



EXAMPLE

No oil imported by 1991. Strong economy, confident people.

10% reduction of present oil imports per year, equitably allocated to states.

Very strict efficiency standards for cars; public transportation. Building energy conservation mandated; low-income weatherization, rehabilitation. Industrial cogeneration, heat recovery.

All necessary funding, tax legislation, regulations; remove all energy subsidies on federal level. Training programs, wide-ranging, intensive public education.

Implementation at federal, state, and local level, with all-out cooperation, strong leadership. Increased domestic oil production only if needed as short-term supplement to appropriate technology.

Automobile stock getting less than 50 mpg replaced; good mass transportation system. Industrial energy use reduced 30-40%; local alcohol fuel plants, recycling, municipal waste use in place. Inner cities revitalized, 3/4 of housing stock upgraded. Low unemployment; inflation below 5% per year; improved environment. Innovative programs at community level getting into full swing; new visions, excitement about possible future achievements.

Plan for Development and Implementation of National Energy Policy, with Example of Results are treated as capital expenditures) versus fossil fuel consumption (which as operating expenses are tax-deductible).

3. Federal funds must be directed towards R&D support for efficiency improvements in industry, including waste heat recovery and cogeneration. Such emerging technologies as thermoelectric/thermal and photovoltaic/thermal cogeneration which produce both electricity and low-grade heat and which promise to be very durable and reliable should receive careful attention. Joint research ventures between government and industry, and tax credits for private R & D should be encouraged. These types of activities have been very successful in Japan. R & D into biomass, especially the use of municipal wastes, as industrial fuels should be encouraged in the near term, also because these can make a major impact in displacing the use of petroleum fuels. I am glad to see that the Committee is devoting an entire day to testimonies in the important biomass area.

4. Since the Federal Government is the largest purchaser of nearly everything, including energy, it should have a steady and persistent program of energy conservation and renewable energy application with strict, but achievable, deadlines. This policy will serve to stimulate the market for renewable energy products and serve as an example for the general public. Most military bases and government facilities that I have visited are very energy-inefficient, and urgent programs with strict guidelines to improve energy efficiency and decrease energy waste implemented after 1973 are being eroded by the present production-oriented administration.

5. Government involvement in active solar systems such as home heating and solar industrial process heat should continue only in the areas of materials and components testing and research and in providing some tax and other financial incentives. Most demonstrations of these solar thermal

technologies have not been successful in generating private sales; they have largely been a waste of money and have in the process also damaged the image of solar energy. Other high-technology projects (thermal power, solar irrigation, etc.) have also been very expensive and have benefited only a few people.

6. The government should consider assisting in the formulation of standards to help industry and the public to achieve confidence in solar thermal equipment and to achieve better efficiencies by quality improvement in the hardware.

7. In addition, there is one solar technology that should be vigorously supported with funding for R & D, that is photovoltaics, especially with the aim of lowering cell and system costs. Photovoltaic systems already have many cost-effective applications and excellent future potential; if our efforts are not continued in this area, the sad experience of our automobile and television manufacturing industries being left behind by foreign competition will be repeated.

As there are many opportunities for more efficient energy use in the commercial/industrial sector, research must address such areas of large potential returns in the near term as heat recovery, district energy planning and use, cascading/cogeneration, and efficiency improvements in motors and controls, there are also many important issues and applied research areas in the residential sector as follows:

1. The emphasis here should be strictly on applied research in weatherization and solarization of housing stock in lower income, urban areas, with emphasis on low-cost methods and materials as well as on programs for implementation (possibly coupled with training programs for unemployed as well as incentives to move away from utility bill subsidies).

2. Another area for applied research, encouraged by strict performance standards, is improved efficiency for lighting and appliances, again with cost goals that compare favorably with less efficient current models. As long as energy-efficient appliances (i.e., refrigerators, clothes washers, etc.) cost 25-40 percent more than a more wasteful model - and the efficient appliances are rarely promoted by advertising or sales - most people (especially builders) simply will not or cannot afford to buy them.

3. Accurate solar data needs to be collected over a long period of time (as has been done by NOAA under a program that must continue to receive funding; funding in this area is essential to provide a reliable data base for passive solar designs).

4. Materials performance research for passive solar applications, with results coordinated in a handbook (and including results and recommendations for different climates) is also needed. For example, answers to such questions as the following would be useful to have: in slab-on-grade floors being used for thermal storage, how is the performance of the concrete affected by the application of 1/8 in. vinyl flooring, 1/4 in. wood parquet, or 1/2 in. quarry tile in different climates, summer and winter? Would an extra 2 in. of concrete above the customary 4 in. be cost-effective with some or all of these options, and where? Research to develop low-cost, low-weight and low-volume, long-life, efficient heat-storage materials is also important, especially to the retrofit market.

5. Low interest mortgages could be used to stimulate both the lagging housing industry as well as energy conservation and passive solar application, if only those homes meeting certain energy performance standards (i.e., 4 $Btu/ft^2$ per degree-day heat loss in a 4000 heating degree day climate and 1/2 $Btu/ft^2$ D.D. auxiliary heating load in January would be eligible for assistance).

There are several advantages in emphasizing a short-term primarily low-technology approach at this time. First of all, investment in this type of research will result in a short payback, where results will be of almost immediate benefit, not only in actual energy savings, but also in wide dispersal throughout the country, industries, the private sector, etc., with new employment opportunities while reducing pressures on the environment and welfare budgets. A pool of qualified technical workers (designers, installers, etc.) would be established which later could advance to more complicated, higher-technology systems (if it should be found necessary at that time). As past experience with the SIPH systems has shown, one major factor contributing to the failure of this program was the lack of competent installation and maintenance personnel. There is another reason why this approach is important, also, and this involves international trade and prestige, especially with Third World countries. It is essential that they begin development based on a renewable energy technology which can be maintained and expanded locally. Unfortunately, this type of technology is viewed there as "second-rate" because that is the message that has been received because of our policies and emphasis here. It is essential for world security that these attitudes be changed. Also, a considerable market would then exist to export software as well as hardware to these developing countries, once these technologies are established here.

It will be possible to achieve such goals without expanding the Federal bureauracy; for instance, the National Science Foundation or other, similar agencies would be able to administer the solar/renewable energy research programs.

Many appropriate technology research and demonstration projects can be undertaken at a fraction of the cost of one large high-technology solar demonstration, where many communities and people would be involved and benefit, either as users, learners, suppliers, etc. in response to local needs and local conditions. The role of the Federal Government should be to encourage states to develop their own programs to involve local communities, small businesses, etc. in cooperative programs of applied research and applications. It is absolutely essential, in terms of the short-and long-range benefits that the United States allocate adequate funding to these developments and establish a fairer balance between the efforts devoted to nuclear research and renewable energy. Ironically, if renewable technology succeeds, (and there is no doubt that it can - with sufficient support), and world peace and world economies will be much less vulnerable, more stable and self-sufficient, and less crisis-prone in the long term. This is essentially the ultimate reason why research in the solar/renewable energy area must continue to receive vigorous funding and corresponding support in policy, legislation, tax law, and education.

In summary, the three areas of priority in renewable energy R D & D that must receive continued, consistent and adequate funding through the 80's are passive solar, biomass, and photovoltaics, coupled with or as part of a general program or climate of emphasis on energy conservation (or better, the wise, appropriate use of energy). A recent SERI study[2] shows that we can cut our present energy consumption by 20 percent in the next twenty years and be more productive, if we just do things more efficiently. An OTA study[3] shows that we can produce between 10 and 20 percent of our energy needs by biomass alone by the year 2000 if we pursue a consistent and steady policy in support of renewable energy resources (including funding for R D & D). Even France, a country that has emphasized nuclear power development, is stepping up its solar/renewable research with a sizable budget increase for next year.

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[2] A New Prosperity, the SERI Solar/Conservation Study, Brick House Publishing, Andover, Massachusetts, 1981.

[3] Energy from Biological Processes, Office of Technology Assessment Report OTA-E-124, July 1980.

The following programs and actions should receive priority in the specified time frame:

1983 and 1984:

Energy conservation; education about appropriate technology, support to small businesses for diversified energy R & D and to community-based projects; state energy policy planning; development of legislative support structure and federal and state levels.

1985 and 1986:

Continuation of strong emphasis on conservation; wide application of lower-cost solar technologies, waste recycling, cogeneration. Training of technical and semi-skilled work force; attention to quality in appropriate technology hardware.

1987 and 1988:

Review of progress; assistance to developing countries with domestically proven systems; reduction of government involvement and overhead.

1989 and 1990:

Emphasis may at this time shift to efficiency improvements in the transportation sector; R D & D support for many promising, new projects in conservation and renewable energy, as well as in environment and materials recycling.

David Rose of MIT wrote recently that "a chicken can hatch its eggs in 21 days, but it must have a steady policy throughout; the job not only cannot be done any quicker but also cannot be done at all, even in 42 days, with a policy of one day on the egg and one day off."

Therefore, especially in times of tight budgetary constraints, it is necessary that R & D support for short-term renewable energy projects continue at an adequate level, even at the cost of having to reduce funding for long-term, high-technology projects. However, even more importantly, such funding must be hand-in-hand with a consistent, supportive energy plan and national policy. As I see it, it is decisions like these that have immense consequences for the future, even though they do not appear all that important at the time.

## DR. EDWARD LUMSDAINE

### Biographical Sketch

Dr. Lumsdaine received his Sc.D in mechanical engineering in 1966 from New Mexico State University. After working as research engineer for Boeing in Seattle, he taught at South Dakota State University for five years. In 1972 he became associate professor of Mechanical and Aerospace Engineering at the University of Tennessee and was promoted to full professor in 1975. In 1977 he took a leave of absence to assume a joint position at New Mexico State University as professor of mechanical engineering and research engineer at the Physical Science Laboratory. He soon was appointed assistant director of the New Mexico Solar Energy Institute and became its director in 1978. At the beginning of this year, he returned to the University of Tennessee as Director of the Energy, Environment, and Resources Center in Knoxville. He has also been a visiting professor at Cairo University in Egypt.

In solar energy, Dr. Lumsdaine has been involved in collector testing and modifications to ASHRAE 93-77 standards; he has designed large solar heating systems for commercial applications and has been involved in workshops for builders, installers and homeowners for residential solar water heating. He was the principal investigator in a Southwest Border Region Commission contract to retrofit passive solar to low-income housing from Brownsville, Texas, to San Diego, California. Another long term project was the development of an Egyptian village using solar and other appropriate technology. He has been a consultant to a number of industries in the design of active and passive solar buildings, in photovoltaics, and in solar industrial process heat applications. He has worked with the New Mexico legislature on appropriate laws to encourage solar applications. His responsibilities as Director of the Solar Institute also involved public education, TV lectures and video tapes, solar design workshops, etc. He has recently completed an assessment of solar industrial process heat for the Florida Solar Energy Center. He has participated in a solar and wind energy workshop in Costa Rica for the National Academy of Sciences; he has been a UNESCO expert consultant in Egypt and since last fall has lectured in Brazil, Colombia, Costa Rica, Egypt, Abu Dhabi, India, Australia and New Zealand on solar and appropriate technology (including wind, small-scale hydro, and biomass) under sponsorship of the U.S. International Communication Agency. He is a member of ASME, ASEE, AIAA, AAUP, ISES, and ASTM (committee member on heating and cooling, passive solar, and photovoltaics)

Mr. HEITOWIT. Dr. Veigel.

Mr. VEIGEL. I appreciate the opportunity to testify before you on this matter of national concern. The difference between the approach you are taking and the approach the executive branch is taking is summarized in my view by pointing out that executive branch decisions on energy are being made by assertion rather than by analysis. A philosophical basis for the assertion does not substitute for an analysis that identifies what is needed and what solutions are available to meet those needs.

In contrast, this symposium testifies to the importance of your gaining perspectives of, for example, State experience that can help shape the Federal program on alternative energy source development. The results of the program that you are responsible for then can better serve the needs of energy consumers.

With a proper focus sustained over time, I firmly believe that an economic renaissance of this country can be fueled by the energy alternatives that we have before us today.

I want to briefly describe the role of the Alternative Energy Corporation because it plays a unique role in the country not found in any other State.

We were established by the Utilities Commission and we are funded by a small surcharge on electric-kilowatt-hour sales.

We operate as a not-for-profit corporation with a twofold mission, to moderate the growth in electric energy demand, and to shift peak loads. We do this by addressing ourselves to the energy end-use sectors and within each of those sectors, figuring out which are the available cost-effective alternative technologies or techniques that can be used to satisfy those needs.

In our definition, conservation, load management, and the technologies based on renewable energy are all included within the range of alternative energy sources.

The clear advantage that this gives us over that of the organization of the Department of Energy, for example, is that we can meet a particular need with the most satisfactory technology by competing the alternative energy technologies available against the conventional technologies that would otherwise be used.

A more detailed description of our corporation is attached to the testimony and submitted for the record.

It is from this context that I am going to address the issues surrounding the need for continuing Federal involvement in renewable energy resources in this decade.

Conventional wisdom tells us that RD&D is a satisfactory description of what is needed. I submit to you that we need to add a third "D" to that list of RD&D; that third D becomes the D of deployment.

Deployment needs to be considered in this listing because it is, more often then not, only briefly considered in Federal decisions concerning the development of renewable resource-based technologies.

Even at the level of research, the expectations of eventual commercialization can help define the choices to be made. I believe over the last decade or so, we have made two serious errors in the way we have gone about developing alternative technologies. The first is to imagine that the major energy issue has been one of technology development and that our end game is defined by the search for the perfect technology as representing the proverbial pot at the end of the rainbow.

The second mistake has been to implicitly assume that the ultimate rationale for commitments to renewable resources has been the feelings of moral virtue and emotional well-being that are supposed to accompany their use. Neither of these assertions is true.

Rather than an interest in the perfect technology, we are interested in the satisfactory technology that at least as satisfactorily meets end-use requirements as the conventional solutions competing for the same market.

Second, while a warm feeling is a pleasant artifact of our use of renewable technologies, we are in fact recommending their use for reasons that are as sensible as any decision made by a cost accountant in an era when economic and environmental consequences are both important.

As a country, we continue to be in the middle of another of our ongoing energy evolutions. However, this one is different than the energy evolutions that have gone before us, because we have a richer set of options than we have ever confronted.

We can now, more precisely and in a more timely manner, meet the needs that we are here to satisfy than has previously been our experience.

This outcome dramatically reenforces the notion that people making decisions as individuals and in their corporate goals can now be more responsible for their own energy futures than has long been possible.

This also attaches importance to what I consider to be the issue of personal responsibility for the consequences flowing from the use of an energy technology. No energy technology, either conventional or alternative, is divine to the extent that we can afford to ignore the question of consequences.

I do not mean by any of my remarks to imply that central station sources of energy are a thing of the past or that our future holds promise of a 100 percent solar national energy picture.

Projects supported by this committee will help establish momentum toward what I describe as a hedged energy strategy. Such a strategy will have as its core the demand that we have the maximum possible diversity of proven energy supply technologies which are economically and technically competitive, and meet requirements of producing consequences that are either acceptable to us or resolvable by us. The diversity inherent in such a strategy will best buffer us against the certainty of an uncertain energy future.

It is within the context of these comments that I would like to get to the heart of my remarks to you today. There are two major areas that I will cover. The first lays out criteria against which programs and projects this committee pursues can and should be judged. Finally, examples of projects that I believe can meet these criteria and merit more work that has been done to date by the Federal Government will be described.

With respect to criteria, I think there are five questions that I would hope you would use in your analysis of projects for the committee to support.

The first of these is to ask, Does the technology convincingly indicate performance, cost and value factors, at least the equal of other technologies with which it will compete.

I think that we are in a situation today in which a decision maker either as an individual, a corporation, or as a government considering alternative energy applications is confronted with a barrage of supposed data and assertions. Yet we have no historical experience to be able to understand or to compare one against another.

Unfortunately, lacking certainty and confused by mutually exclusive counterclaims, the typical reaction is one of paralysis or a commitment to the familiar.

I think that we have ways at hand to produce higher quality and better decisions about which technology, conventional or renewable, should be chosen to meet a particular end-use need.

One of the ironies of research and development in alternative technologies has been that we have permitted mutually exclusive claims for competitive technologies to be made. We are surely past the point where we can afford the luxury of such illusions. Even the otherwise best of technologies may not succeed because the coincidence of its timing may mean that a competitor will already have become too firmly established to be dislodged by a technology only its equivalent or its marginal better.

The total supply must afterall be defined by total demand.

To remedy this problem, I propose continuation of work sponsored initially a few years ago at the Solar Energy Research Institute. The desired result there was an analytic tool usable at all levels for legitimate comparisons of competitive technologies, again both conventional and alternative.

The documented methodology will have assumptions that are visible and a methodology that itself is totally transparent. Comparisons can then be made in terms of delivered energy cost, operations and maintenance, insurance costs, rates of return, et cetera.

This work is deserving of significant support because its outcome will go far in rationalizing the kind of market structure that can most effectively meet our energy needs.

You will, I am sure, face assertions by the developers of technologies that this should not be done. However large the error bands around the final numbers that may result from doing this competitive comparison, they will be relatively better than either no numbers at all or numbers based only on the assertions of the fanatic of a particular technology.

The second criteria is to ask whether the competitiveness of a new energy system, can be enhanced by building on its complementarity with other technologies.

No energy system exists in a vacuum. We need to pay a great deal more attention to the complementarity of one technology with another.

Many technologies undergoing separate development today will find their richest opportunities in applications where their strengths can be complemented by the strengths of other technologies. Applied together, they can meet a need more effectively than any single technology.

Examples are beginning to abound but more can be done. Heat pumps can be added to residences, geothermal used preheat for boiler operations, et cetera.

The third criteria is to ask whether quality assurance issues are properly considered. I think many of the programs that have been done by the Department of Energy lack work in quality assurance. Many solutions to the problems that disable technologies they were out to demonstrate could have been resolved ahead of time had they paid proper attention to issues of quality assurance.

The fourth criteria is to ask the purpose a demonstration is meant to serve. We have had a rich amount of confusion in energy demonstrations over the past decade because we tried to mix purposes in ways that are totally nonproductive.

Demonstrations either serve the needs of the basic scientists, the needs of the policy decision maker trying to ratify the value of decisions made, or the needs of the end-use applier of that technology. The demonstrations for each are quite different. We mix these up at our peril.

As a final criteria and perhaps one of the most important, I think we need to address, whether issues with respect to energy and load requirements are being met.

The DOE for years has paid considerable attention to issues surrounding energy conservation either in conserving Btu's, gallons of fuel or tons of coal. We need to do this; but we also need to recognize that in many States the considerably more important issue than energy conservation itself is the issue of how the load is managed and how do we create capacity deferrals.

New energy supply technologies and energy conserving systems have the capability to defer the need for a utility to construct additional central station capacity. These alternative systems are becoming to many utilities a more and more rationale economic conclusion as they face the reality that Wall Street is unable and/or unwilling to raise the capital investments now needed for large-scale facilities.

The continuing unwillingness of the Department of Energy to recognize the importance of load and capacity is demonstrated by examples in the southeast where essential information needed was denied in the shortsighted drive to collect information only with respect to total energy consumption and with no measure of its time dependence.

Many of the renewable-based technologies that are your responsibility are perfectly suited to applications where there is relatively small scale and relatively short construction time compared in both cases to that of large central station facilities. Thus makes perfectly possible a much more precise scale and time matching of new energy supply to growing energy demand.

I would like to conclude by making brief remarks with respect to the end use sectors in which I think more work can be done and hopefully supported by your committee.

Obviously in the residential area, the goal is to minimize the import of energy into the home. Albeit a minimization consistent with technical and economic equity both to the homeowner and to the utility providing the energy that the homeowner is unwilling or unable to provide for himself.

The action that the homeowner must take ought to fit most easily and naturally into the energy expectations that the homeowner has, and the amount of day-to-day involvement that homeowners must have in operating their systems will significantly impact their willingness to accommodate to new energy systems.

For instance, we must develop better education for so-called passive solar features now being designed. Homeowners who with the best of intentions sabotage the energy effectiveness of their homes illustrate the need for the necessary interactions with the homeowner with the operation of energy technologies on the customer's side of the meter.

We need also in the residential area to look at both low cost and hybrid renewable technologies. Particularly in the southeast hybrid technologies such as the combination of super insulated home with passive solar technologies may be worthwhile. Beyond the normal benefits such a home will have, I think we will find cooling load reductions and hopefully, issues in humidity control. Finally, we must not let pass the issues with respect to indoor air quality.

At the utility level, I think there are two major issues, the first being the contribution that alternative energy can make to strategic utility planning is totally underrepresented today. Decisions are being made on our out-year commitments for 10 and 15 years from now in the total absence of any serious consideration with respect to alternative energy. unfortunately no one yet has a tool in hand that will allow them to draw these conclusions at a level of sophistication equivalent to their ability to consider coal and nuclear power plants.

The integration of renewables into outyear utility planning will help insure the inevitability of their success.

In utilities also, I strongly support work in continuing the ability to show utilities that wind energy conversion, can often be a prefered alternative. While it is at the edge of being effectively handled by the private sector, we need to continue in a very precise way in adding skills and tools to the ability of the private sector to make its own decisions about wind energy.

In photovoltaic systems, balance of system questions in substations for both residential and substation level application needs to be resolved.

In the industrial arena, a cogeneration is far and away the area that needs the greatest continuing support. Both for things like alternative resource fuels like wood and/or for the means by which various resources are converted into an energy source, for intance by pressurized or atmospheric fluidized bed combustion.

Now commercial and industrial energy storage technologies for space conditioning, process heat and electric generation is receiving adequate support today. I think a basic opportunity in the industrial arena lies in the creation of what I call energy enterprise zones, similar in means but different in execution to economic enterprise zones.

In general, in industry our present situation is driving us toward extensive refurbishment of the capital stock of the United States. We have an unparalleled opportunity here to regain some of the commanding lead we have lost by proper attention to the ability of new energy technologies to change the very nature of the processes we use in producing goods and services.

Alternative energy technologies help us do not only things we are used to doing, but doing them better and more effectively. They can also stimulate us to the opportunities we face in doing things in materially different ways.

In conclusion, I believe the maturity of the alternative energy development process so painfully created over the last few years has resulted in our seeing some technologies well on their way to becoming formerly alternative and newly conventional. Our national security demands that we persist in our drive to expand the availability of alternative energy technologies on the basis of sensible criteria.

I have appreciated this chance to share my perspective with you. My hope is that you continue to solicit input from practitioners in the field. In particular, I would recommend that you consider scheduling a later hearing to provide you with an external review and critique of the DOE study now underway on this same topic that is being undertaken at your instigation.

Thank you.

[The prepared statement of Jon Veigel follows:]

# TESTIMONY OF JON M. VEIGEL
EXECUTIVE DIRECTOR
NORTH CAROLINA ALTERNATIVE ENERGY CORPORATION

BEFORE THE SUBCOMMITTEE ON ENERGY DEVELOPMENT AND APPLICATIONS,
HOUSE COMMITTEE ON SCIENCE AND TECHNOLOGY
FIELD HEARING ON "RENEWABLE ENERGY IN THE EIGHTIES:
NEEDS FOR FURTHER RESEARCH, DEVELOPMENT AND DEMONSTRATION"

UNITED STATES PAVILION
THE 1982 WORLD'S FAIR
KNOXVILLE, TENNESSEE
28 MAY 1982

THANK YOU FOR THE OPPORTUNITY TO TESTIFY ON THIS IMPORTANT AREA OF CONTINUING NATIONAL CONCERN. AS THE EXECUTIVE DIRECTOR OF THE NORTH CAROLINA ALTERNATIVE ENERGY CORPORATION (AEC), I BELIEVE THERE ARE IMPORTANT PERSPECTIVES OF STATE EXPERIENCE THAT CAN HELP SHAPE THE FEDERAL PROGRAM IN ALTERNATIVE ENERGY RESOURCE DEVELOPMENT. THE RESULTS OF THE PROGRAM CAN THEN BETTER SERVE THE NEEDS OF ENERGY CONSUMERS. WITH A PROPER FOCUS SUSTAINED OVER TIME I AM CONVINCED AN ECONOMIC RENAISSANCE OF THIS COUNTRY CAN BE FUELED BY THE ALTERNATIVE ENERGY OPTIONS WE HAVE.

I WOULD LIKE TO BEGIN BY BRIEFLY DESCRIBING THE ROLE OF THE AEC IN ALTERNATIVE ENERGY DEVELOPMENT. THE AEC WAS ESTABLISHED BY THE NORTH CAROLINA UTILITIES COMMISSION IN 1980. WE ARE FUNDED BY A SMALL SURCHARGE ON KILOWATT-HOUR SALES OF ALL ELECTRICITY SOLD IN NORTH CAROLINA. THIS REVENUE SOURCE ANNUALLY BRINGS US ABOUT 45 CENTS PER PERSON IN THE STATE, OR A TOTAL OF ABOUT TWO AND A QUARTER MILLION DOLLARS PER YEAR.

WE OPERATE AS A NOT-FOR-PROFIT CORPORATION WITH BASIC OBJECTIVES TO MODERATE THE GROWTH IN ELECTRIC ENERGY DEMAND AND TO SHIFT PEAK LOADS. OUR OBJECTIVES WILL BE REALIZED BY OUR WORKING IN ENERGY END-USE SECTORS. WITHIN EACH END-USE SECTOR ENERGY NEEDS THAT CAN BE MET BY AN AVAILABLE COST-EFFECTIVE ALTERNATIVE TECHNOLOGY OR TECHNIQUE ARE THEN IDENTIFIED. WE CONSIDER CONSERVATION, LOAD MANAGEMENT, AND TECHNOLOGIES BASED ON RENEWABLE ENERGY SOURCES AS INCLUDED IN THE RANGE OF ALTERNATIVE ENERGY RESOURCES. THE CLEAR ADVANTAGE THIS GIVES US IS THE ABILITY TO SELECT THE MOST SATISFACTORY TECHNOLOGY TO MEET THE PARTICULAR NEED BY COMPETING THE ALTERNATIVE TECHNOLOGIES NOW AVAILABLE AGAINST THE CONVENTIONAL TECHNOLOGIES THAT WOULD OTHERWISE BE UTILIZED. A MORE DETAILED DESCRIPTION OF THE PROGRAM RATIONALE AND PROJECTS OF THE ALTERNATIVE ENERGY CORPORATION IS ATTACHED TO THIS TESTIMONY AND SUBMITTED FOR THE RECORD.

IT IS FROM THIS CONTEXT THAT I AM GOING TO ADDRESS THE ISSUES SURROUNDING THE CONTINUING NEED FOR FEDERAL INVOLVEMENT IN RENEWABLE ENERGY RESOURCES IN THIS DECADE. CONVENTIONAL WISDOM TELLS US THAT "RESEARCH, DEVELOPMENT AND DEMONSTRATION" FORM A COMPLETE DESCRIPTION OF THE AREAS OF INTEREST AND IMPORTANCE. I SUBMIT THAT A THIRD "D" NEEDS TO BE ADDED TO "R, D AND D". THAT "D" IS THE "D" OF DEPLOYMENT. DEPLOYMENT NEEDS TO BE CONSIDERED IN THIS LISTING BECAUSE IT IS MORE OFTEN THAN NOT ONLY BRIEFLY CONSIDERED IN FEDERAL DECISIONS CONCERNING THE DEVELOPMENT OF RENEWABLE RESOURCE-BASED

TECHNOLOGIES. EVEN AT THE LEVEL OF RESEARCH, THE EXPECTATIONS OF EVENTUAL COMMERCIALIZATION CAN HELP DEFINE THE CHOICES TO BE MADE.

MY OBSERVATIONS OF FEDERAL INVOLVEMENT IN RENEWABLE ENERGY RESOURCES OVER THE PAST DECADE HAVE CONVINCED ME THAT, AS A NATION, WE HAVE MADE TWO SERIOUS ERRORS. THE FIRST IS TO IMAGINE THAT THE MAJOR ENERGY ISSUE HAS BEEN ONE OF TECHNOLOGY DEVELOPMENT AND THAT THE SEARCH FOR THE "PERFECT" TECHNOLOGY REPRESENTS THE PROVERBIAL POT AT THE END OF THE RAINBOW. THE SECOND MISTAKE HAS BEEN TO IMPLICITLY ASSUME THAT THE ULTIMATE RATIONALE FOR COMMITMENTS TO RENEWABLE RESOURCES IS THE FEELING OF MORAL VIRTUE AND EMOTIONAL WELL-BEING THAT ACCOMPANY THEIR USE. NEITHER OF THESE ASSERTIONS IS TRUE. WE ARE NOT PRIMARILY INTERESTED IN DEVISING THE PERFECT TECHNOLOGY. WE ARE INTERESTED IN DEVELOPING A TECHNOLOGY THAT MEETS THE REQUIREMENTS OF THE ENERGY NEED TO BE MET AT LEAST AS SATISFACTORILY AS THE CONVENTIONAL SOLUTIONS COMPETING FOR THE SAME MARKET. SECONDLY, WHILE A WARM FEELING IS A PLEASANT ARTIFACT OF OUR USE OF RENEWABLE TECHNOLOGIES, WE ARE IN FACT RECOMMENDING THEIR USE FOR REASONS THAT ARE AS COLD-HEARTED AND GIMLET-EYED AS ANY DECISION MADE IN AN ERA WHEN ECONOMIC AND ENVIRONMENTAL CONSEQUENCES ARE IMPORTANT.

AS A COUNTRY WE ARE IN THE MIDDLE OF ANOTHER OF OUR CONTINUING SERIES OF ENERGY EVOLUTIONS. THIS ONE IS MATERIALLY DIFFERENT FROM THOSE THAT HAVE GONE BEFORE. BECAUSE WE HAVE A WIDER RANGE OF ALTERNATIVE TECHNOLOGIES TO CHOOSE FROM, WE HAVE A RICHER SET OF ENERGY OPTIONS THAN EVER BEFORE. WHAT IS AVAILABLE TO US TODAY ALSO ALLOWS US TO MORE PRECISELY, AND IN A MORE TIMELY MANNER, MEET THE NEEDS THAT WE ARE HERE TO SATISFY THAN HAS PREVIOUSLY BEEN OUR EXPERIENCE. THIS OUTCOME DRAMATICALLY REINFORCES THE NOTION THAT PEOPLE MAKING DECISIONS, AS INDIVIDUALS AND IN THEIR CORPORATE ROLES, CAN BE

MORE RESPONSIBLE FOR THEIR ENERGY FUTURES THAN HAS LONG BEEN POSSIBLE. THIS IS PARTICULARLY IMPORTANT IF WE ALSO RECOGNIZE THE ISSUE OF PERSONAL RESPONSIBILITY FOR THE CONSEQUENCES FLOWING FROM THE USE OF AN ENERGY TECHNOLOGY. NO ENERGY TECHNOLOGY, EITHER CONVENTIONAL OR ALTERNATIVE, IS BENIGN TO THE EXTENT THAT WE CAN AFFORD TO IGNORE THE QUESTION OF WHAT ARE THE CONSEQUENCES OF THE USE OF THESE TECHNOLOGIES, WHO IS RESPONSIBLE FOR THOSE CONSEQUENCES, AND WHAT IS NECESSARY FOR US TO RESOLVE OR ACCOMMODATE TO THE CONSEQUENCES.

I DO NOT MEAN TO IMPLY THAT CENTRAL-STATION SOURCES OF ENERGY ARE A THING OF THE PAST, NOR THAT OUR FUTURE HOLDS PROMISE OF A ONE HUNDRED PERCENT SOLAR COMPONENT OF OUR NATIONAL ENERGY SUPPLY PICTURE. PROJECTS SUPPORTED BY THIS COMMITTEE WILL HELP ESTABLISH MOMENTUM TOWARD A HEDGED ENERGY STRATEGY. SUCH AN ENERGY STRATEGY WOULD HAVE AT ITS CORE THE DEMAND THAT WE HAVE THE MAXIMUM POSSIBLE DIVERSITY OF PROVEN ENERGY SUPPLY TECHNOLOGIES WHICH ARE ECONOMICALLY AND TECHNICALLY COMPETITIVE, AND MEET REQUIREMENTS OF PRODUCING CONSEQUENCES THAT ARE EITHER ACCEPTABLE TO US OR RESOLVABLE BY US. THE DIVERSITY INHERENT IN SUCH A STRATEGY WILL BEST BUFFER US AGAINST THE CERTAINTY OF AN UNCERTAIN ENERGY FUTURE. WE WILL THEN FIND OURSELVES WITH THE MAXIMUM POSSIBLE CHANCES TO RESPOND IN THE SHORTEST POSSIBLE TIME TO WHATEVER REALITIES OUR ENERGY FUTURE BRINGS.

IT IS WITHIN THE CONTEXT OF THESE COMMENTS THAT I WOULD LIKE TO GET TO THE HEART OF MY REMARKS TO YOU TODAY. THERE ARE TWO MAJOR AREAS THAT I WILL COVER. THE FIRST LAYS OUT CRITERIA AGAINST WHICH PROGRAMS AND PROJECTS THIS COMMITTEE PURSUES CAN BE JUDGED. EXAMPLES OF PROJECTS THAT I BELIEVE CAN

MEET THESE CRITERIA AND MERIT MORE WORK THAN HAS BEEN DONE TO DATE BY THE FEDERAL GOVERNMENT MAKE UP THE SECOND AREA. THERE ARE FIVE QUESTIONS IN LIGHT OF WHICH ALL PROPOSED PROJECTS SHOULD BE EVALUATED:

1) **DOES THE TECHNOLOGY CONVINCINGLY INDICATE PERFORMANCE, COST, AND VALUE FACTORS AT LEAST THE EQUAL OF OTHER TECHNOLOGIES WITH WHICH IT WILL COMPETE?** IN MOST MARKET SITUATIONS TODAY THE EXPECTATION OF THE AMERICAN PUBLIC IS THAT THERE WILL BE FIERCE CLAIMS AND COUNTERCLAIMS ABOUT COMPETING PRODUCTS. HOWEVER, THE EXTENSION OF THAT SAME BEHAVIOR PATTERN TO THE FIELD OF RENEWABLE ENERGY RESOURCES HAS ITSELF BEEN THE SOURCE OF SIGNIFICANT PROBLEMS. WE HAVE HAD NO WIDE EXPERIENCE WITH THESE NEW ENERGY SYSTEMS TO SERVE AS A FOUNDATION FOR INFORMED JUDGMENTS. NOR DO WE NOW HAVE THE ANALYTIC MEANS TO ESTABLISH THE CREDIBILITY OF ONE TECHNOLOGY AGAINST ANY OTHER TECHNOLOGY ADDRESSED TO THE SAME END-USE NEED. THE PROPONENTS FOR A PARTICULAR ALTERNATIVE TECHNOLOGY EACH HAVE NUMBERS THEY CLAIM DEMONSTRATE CONCLUSIVELY WHY THE PERFORMANCE, COST, AND VALUE OF THEIR PARTICULAR TECHNOLOGY EXCEEDS ANY OTHER. WHEN A DECISIONMAKER FOR EITHER INDIVIDUAL, CORPORATE, OR GOVERNMENT ALTERNATIVE ENERGY APPLICATIONS IS CONFRONTED WITH THIS BARRAGE IN AN AREA AS NEW AS RENEWABLE RESOURCES, I BELIEVE THE TYPICAL REACTION IS ONE OF PARALYSIS OR A COMMITMENT TO THE FAMILIAR. LACKING CERTAINTY, AND CONFUSED BY MUTUALLY EXCLUSIVE COUNTERCLAIMS, THERE IS AT PRESENT NO WAY TO PRODUCE HIGHER QUALITY AND BETTER DECISIONS ABOUT WHICH TECHNOLOGY, CONVENTIONAL OR RENEWABLE, SHOULD BE CHOSEN TO MEET A PARTICULAR ENERGY NEED.

WHILE ONE OF THE IRONIES OF RESEARCH AND DEVELOPMENT IN ALTERNATIVE TECHNOLOGIES HAS BEEN THESE MUTUALLY EXCLUSIVE CLAIMS FOR COMPETITIVE TECHNOLOGIES, WE ARE NOW SURELY PAST THE POINT WHERE WE CAN AFFORD THE LUXURY OF SUCH ILLUSIONS. EVEN THE OTHERWISE BEST OF TECHNOLOGIES MAY NOT SUCCEED BECAUSE THE COINCIDENCE OF TIMING MAY MEAN THAT A COMPETITOR WILL ALREADY HAVE BECOME TOO FIRMLY ESTABLISHED TO BE DISLODGED BY A TECHNOLOGY ONLY ITS EQUIVALENT OR ITS MARGINAL BETTER. THE TOTAL SUPPLY MUST, AFTER ALL, BE DEFINED BY TOTAL DEMAND.

TO REMEDY THIS PROBLEM I PROPOSE WORK SPONSORED BY THIS COMMITTEE THAT WOULD CONTINUE VERY INITIAL WORK BEGUN TWO YEARS AGO BY THE SOLAR ENERGY RESEARCH INSTITUTE. THE DESIRED RESULT WAS, AND IS, AN ANALYTIC TOOL USEABLE AT ALL LEVELS FOR LEGITIMATE COMPARISONS OF COMPETING TECHNOLOGIES, BOTH CONVENTIONAL AND RENEWABLE. THE DOCUMENTED METHODOLOGY WILL HAVE ASSUMPTIONS WHICH ARE VISIBLE, AND A METHODOLOGY THAT IS ITSELF TOTALLY TRANSPARENT. COMPARISONS CAN THEN BE MADE BETWEEN AND AMONG TECHNOLOGIES IN TERMS OF THEIR DELIVERED ENERGY COSTS, OPERATION AND MAINTENANCE, INSURANCE COSTS, INTERNAL RATE OF RETURN, ETC.

THIS WORK IS DESERVING OF SIGNIFICANT SUPPORT BECAUSE ITS OUTCOME WILL GO FAR IN RATIONALIZING THE KIND OF MARKET STRUCTURE THAT CAN MOST EFFECTIVELY MEET OUR ENERGY NEEDS. THE ASSERTION BY THE DEVELOPER OF THE TECHNOLOGY THAT THIS SHOULD NOT BE DONE MUST BE RESISTED. HOWEVER LARGE THE ERROR BANDS AROUND THE FINAL NUMBERS, THEY WILL BE RELATIVELY BETTER THAN NO NUMBERS AT ALL.

2) **CAN THE COMPETITIVENESS OF A NEW ENERGY SYSTEM BE ENHANCED BY BUILDING ON ITS COMPLEMENTARITY WITH OTHER TECHNOLOGIES?** NO ENERGY SYSTEM, CONVENTIONAL OR ALTERNATIVE, EXISTS IN A VACUUM. WE NEED TO PAY A GREAT DEAL MORE ATTENTION TO THE COMPLEMENTARITY OF ONE TECHNOLOGY WITH ANOTHER. MANY TECHNOLOGIES UNDERGOING SEPARATE DEVELOPMENT WILL FIND THEIR RICHEST OPPORTUNITIES IN APPLICATIONS WHERE THEIR STRENGTHS CAN BE COMPLEMENTED BY THE STRENGTHS OF OTHER TECHNOLOGIES. APPLIED TOGETHER THEY CAN MEET A NEED MORE EFFECTIVELY THAN ANY SINGLE TECHNOLOGY. EXAMPLES OF ADD-ON HEAT PUMPS TO RESIDENTIAL GAS FURNACES, GEOTHERMAL ENERGY AS A PRE-HEAT FOR BOILERS, ETC. ILLUSTRATE THE POSSIBILITIES.

3) **ARE QUALITY ASSURANCE ISSUES PROPERLY CONSIDERED?** THIS CRITERION IS NORMALLY DEFINED IN THE EYES OF THE BEHOLDER. MOST OF THE INTENSE DEVELOPMENT OF ALTERNATIVE ENERGY TECHNOLOGIES HAS FOCUSED ON THE BASIC SCIENTIFIC RESEARCH

AND EARLY ENGINEERING DEVELOPMENT. IT IS PERHAPS NO SURPRISE, THOUGH A MISTAKE, THAT WE PAID TOO LITTLE ATTENTION TO ISSUES SURROUNDING QUALITY ASSURANCE OF THE LIKELY FINAL PRODUCT IN TERMS OF ITS USEFULNESS IN THE MARKETPLACE.

IN MY PREVIOUS POSITION MANAGING A DIVISION AT THE SOLAR ENERGY RESEARCH INSTITUTE I WAS RESPONSIBLE FOR SERI'S QUALITY ASSURANCE ACTIVITIES. WE WERE OFTEN FRUSTRATED BY THE SELF-INFLICTED PROBLEMS DOE HAD WITH SOME OF ITS HIGH TECHNOLOGY DEMONSTRATIONS PRECISELY BECAUSE THEY HAD NOT GIVEN ADEQUATE CONSIDERATION TO THE ISSUES RAISED BY QUALITY ASSURANCE. IN SOME CASES PROBLEMS FACED DURING ENGINEERING DEVELOPMENT COULD EASILY HAVE BEEN RESOLVED BY SOLUTIONS ALREADY IN COMMONPLACE USE IN OTHER ENGINEERING APPLICATIONS; SOLUTIONS, HOWEVER, THAT DUE TO THE FAILURE TO FOLLOW AN ADEQUATE QUALITY ASSURANCE PROGRAM WERE NEVER DISCOVERED OR IMPLEMENTED.

4) WHAT PURPOSE IS A DEMONSTRATION MEANT TO SERVE? DEMONSTRATIONS HAVE LONG BEEN A FAVORITE VEHICLE, PARTICULARLY IN ENERGY, FOR PROMOTING THE EARLY VISIBILITY OF NEW TECHNOLOGIES. PROBLEMS HAVE ARISEN, HOWEVER, WHEN INADEQUATE ATTENTION IS GIVEN TO RECOGNITION THAT DEMONSTRATIONS MUST HAVE A CLEARLY FOCUSED PURPOSE TO BE EFFECTIVE. DEMONSTRATIONS CAN SERVE THE NEEDS OF THE ENGINEERS AND SCIENTISTS IN EARLY STAGES OF RESEARCH AND

TECHNOLOGY DEVELOPMENT TO ANSWER BASIC QUESTIONS, OR THEY CAN SERVE THE NEEDS OF DECISIONMAKERS IN EVALUATING POLICY OPTIONS, OR THEY CAN DEMONSTRATE TO THE POTENTIAL END-USER THE EFFECTIVENESS OF AN APPLICATION OF A PARTICULAR TECHNOLOGY. TO THE EXTENT THAT THESE CATEGORIES ARE BLURRED, TO THAT EXTENT THE DEMONSTRATION WILL BECOME MORE OR LESS UNSATISFACTORY TO ALL PARTIES CONCERNED, EACH OF WHOM WILL FAIL TO FIND MANY OF THEIR QUESTIONS ANSWERED. I BELIEVE THE GREATER ATTENTION TO THESE THREE CATEGORIES OF DEMONSTRATIONS BY THIS COMMITTEE WILL RESULT IN A MORE COHERENT MOMENTUM TOWARDS THE EVENTUAL COMMERCIALIZATION OF THE TECHNOLOGIES YOU SUPPORT.

5) **DOES THE ALTERNATIVE ELECTRIC TECHNOLOGY MEET BOTH ENERGY AND LOAD REQUIREMENTS?** FOR MANY YEARS THE PRIMARY FOCUS OF THE DEPARTMENT OF ENERGY HAS BEEN SAVING ENERGY--IN CONSERVING BTUS, GALLONS OF FUEL, TONS OF COAL. WHILE THIS IS A NECESSARY CONCERN, IT IS BY NO MEANS SUFFICIENT. FOR MANY STATES, MUCH MORE IMPORTANT ISSUES THAN SAVING ENERGY ARE BETTER MANAGEMENT OF LOAD AND CREATING CAPACITY DEFERRALS. THAT NEW ENERGY SUPPLY TECHNOLOGIES OR ENERGY-CONSERVING SYSTEMS HAVE THE CAPABILITY TO DEFER THE NEED FOR A UTILITY TO CONSTRUCT ADDITIONAL CENTRAL-STATION SCALE CAPACITY IS BECOMING A MORE AND MORE RATIONAL ECONOMIC CONCLUSION BY UTILITY COMPANIES UNABLE TO RAISE CAPITAL INVESTMENT FUNDS FOR LARGE-SCALE FACILITIES.

> THE UNWILLINGNESS OF THE DEPARTMENT OF ENERGY TO RECOGNIZE THE IMPORTANCE OF LOAD AND CAPACITY QUESTIONS HAS RESULTED IN DOE PROJECTS IN THE SOUTHEAST WHERE THE ESSENTIAL INFORMATION NEEDED BY THE UTILITY SECTOR WAS DENIED IN THE SHORT-SIGHTED DRIVE TO COLLECT INFORMATION ONLY WITH RESPECT TO TOTAL ENERGY CONSUMPTION, WITH NO MEASURE OF ITS TIME DEPENDENCE. MANY OF THE RENEWABLE-BASED TECHNOLOGIES THAT ARE YOUR RESPONSIBILITY ARE PERFECTLY SUITED TO APPLICATIONS WHERE THEIR RELATIVELY SMALL SCALE AND RELATIVELY SHORT CONSTRUCTION TIME, COMPARED IN BOTH CASES TO THAT OF LARGE CENTRAL-STATION FACILITIES, MAKE PERFECTLY POSSIBLE A MUCH MORE PRECISE SCALE AND TIME MATCHING OF NEW ENERGY SUPPLY TO GROWING ENERGY DEMAND.

WHILE THE MAIN THRUST OF MY REMARKS SO FAR HAS BEEN TO DEFINE THESE CRITICAL QUESTIONS, I WOULD LIKE TO BRIEFLY MENTION SOME EXAMPLES IN THE VARIOUS END-USE SECTORS WHICH I THINK ARE PARTICULARLY APPROPRIATE FOR EITHER CONTINUED COMMITTEE SUPPORT OR NEW COMMITTEE SUPPORT.

IN THE RESIDENTIAL AREA THE BASIC MOTIVATION FOR THE DEVELOPMENT OF THE DECENTRALIZED TECHNOLOGIES YOU ARE RESPONSIBLE FOR IS TO MINIMIZE THE AMOUNT OF ENERGY IMPORTED INTO THE HOME, CONSISTENT WITH TECHNICAL AND ECONOMIC EQUITY. EQUITY IS IMPORTANT BOTH FOR THE HOMEOWNER AND FOR THE RATEPAYERS SUPPORTING THE UTILITY WHICH HAS THE ULTIMATE RESPONSIBILITY UNDER PRESENT CONDITIONS FOR PROVIDING ENERGY TO THE HOMEOWNER UNWILLING OR UNABLE TO PROVIDE FOR HIMSELF. EQUITY AIMS TO MINIMIZE COSTS AND MAXIMIZE BENEFITS FOR BOTH THE INDIVIDUAL CUSTOMER AND THE UTILITY'S RATEPAYERS.

IN THIS SENSE, CONSIDERABLY MORE ATTENTION NEEDS TO BE PAID TO THE DEVELOPMENT OF TECHNOLOGIES WHICH WILL MORE EASILY FIT THEMSELVES NATURALLY INTO THE ENERGY EXPECTATIONS THAT HOMEOWNERS HAVE. THE ACTIONS THEY MUST TAKE TO PROVIDE THEMSELVES WITH A COMFORTABLE LIVING ENVIRONMENT AND THE QUALITY AND QUANTITY OF ENERGY SUFFICIENT TO MEET ALL OF THEIR REQUIREMENTS IMPACT SIGNIFICANTLY THEIR WILLINGNESS TO ACCOMMODATE TO NEW ENERGY SYSTEMS. MANY OF THE TECHNOLOGIES RECEIVING ATTENTION TODAY REQUIRE MORE DIRECT PARTICIPATION BY THE HOMEOWNER THAN I THINK IS EITHER NECESSARY OR USEFUL. WE DARE NOT DEPEND ON EMOTIONAL FERVOR OR POLITICAL COMMITMENT TO ANY PARTICULAR TYPE OF TECHNOLOGY FOR THE EVENTUAL WIDESPREAD SUCCESS OF THAT TECHNOLOGY.

FOR INSTANCE, WE MUST DEVELOP BETTER MEANS FOR EASY CONTROL OF THE SO-CALLED PASSIVE SOLAR FEATURES NOW BEING DESIGNED IN MANY NEW HOMES AND IN SOME CASES RETROFITED TO EXISTING HOMES. HOMEOWNERS WHO, WITH THE BEST OF INTENTIONS, SABOTAGE THE ENERGY EFFECTIVENESS OF THEIR HOMES ILLUSTRATE THE NEED FOR MINIMIZING THE NECESSARY INTERACTIONS OF THE HOMEOWNER WITH THE OPERATION OF ENERGY TECHNOLOGIES ON THE CUSTOMER'S SIDE OF THE METER.

INCREASED ATTENTION SHOULD BE PAID TO THE DEVELOPMENT OF BOTH LOW-COST AND HYBRID RENEWABLE TECHNOLOGIES. TECHNOLOGIES DEVELOPED FOR THEIR LOW COST AND CONSEQUENT ENHANCED ECONOMIC COMPETITIVENESS HAVE MAJOR ADVANTAGES OVER THOSE TECHNOLOGIES ALL TOO OFTEN DEVELOPED WHERE THE MAJOR FOCUS IS SOPHISTICATED TECHNOLOGY. TOO LITTLE WORK HAS BEEN DONE TO DATE ON HYBRID TECHNOLOGIES APPLICABLE IN THE SOUTHEAST. ONE EXCELLENT PROSPECT IS TO COMBINE THE SUPERINSULATED HOME WITH PASSIVE SOLAR TECHNOLOGY -- ALL DIRECTED TOWARDS NOT

ONLY ENERGY AND LOAD CONTROL ISSUES BUT ALSO THE ATTENDANT ISSUE OF HUMIDITY CONTROL. SUPERINSULATED HOMES MAY HAVE SOME POSITIVE IMPACT ON REDUCING COOLING LOADS AS WELL. FINALLY, WE MUST NOT LET ATTENTION DISSIPATE FROM THE ISSUE SURROUNDING DECREASED INDOOR AIR QUALITY WHERE VERY TIGHT HOMES HAVE LOW AIR EXCHANGE RATES.

IN THE UTILITY AREA THERE ARE TWO ISSUES THAT I THINK DESERVE ATTENTION. AT THE LEVEL OF STRATEGIC UTILITY PLANNING, NO TOOL CURRENTLY EXISTS THAT ALLOWS UTILITY PLANNERS TO EFFECTIVELY INTEGRATE ANY CONSIDERATION OF THE LIKELY IMPACT OF RENEWABLE TECHNOLOGIES ON THEIR CAPACITY EXPANSION PLANNING, THEIR PRODUCTION COST MODELING, ETC. THE INTEGRATION OF RENEWABLES INTO OUT-YEAR UTILITY PLANNING WILL HELP ENSURE THE INEVITABILITY OF THEIR SUCCESS.

MORE WORK NEEDS TO BE DONE TO DEVELOP THE DATA TO ESTABLISH THE CREDIBILITY OF CENTRAL-STATION SCALE WIND FARM ENERGY GENERATION IN THE EYES OF UTILITY DECISIONMAKERS. WHILE THE MOMENTUM FOR WECS TECHNOLOGY DEVELOPMENT IS AT THE RAGGED EDGE OF BEING EFFECTIVELY HANDLED BY THE PRIVATE SECTOR, THIS MOMENTUM IS IN DANGER OF FALTERING UNDER OUR PRESENT HIGH INTEREST RATE CONDITIONS. I BELIEVE IT IS ESSENTIAL FOR FURTHER FEDERAL WORK TO HELP REDUCE THE APPARENT RELATIVE RISK WITH WHICH THESE TECHNOLOGIES ARE VIEWED BY UTILITY DECISIONMAKERS. ONE KEY PART OF SUCH DEVELOPMENT WILL BE FURTHER WORK ALONG THE LINES OF THAT BY THE PACIFIC NORTHWEST LABS AND SERI TO CONVERT WIND RESOURCE DATA INTO WIND ENERGY RESOURCE DATA. NEITHER THE DATA NOR THE TECHNIQUES SUFFICIENT TO ALLOW A UTILITY TO JUDGE WITH RELIABILITY THE CONTRIBUTION THAT WIND WILL MAKE TO MEETING ITS LOAD DEMANDS ARE YET CONVENIENTLY AVAILABLE.

CONTINUED SUPPORT FOR PHOTOVOLTAIC SYSTEMS DEVELOPMENTS IS IMPORTANT. BALANCE-OF-SYSTEM ISSUES FOR RESIDENTIAL AND SUB-STATION LEVEL APPLICATIONS NEED TO BE RESOLVED. IN THE INDUSTRIAL ARENA, I BELIEVE THE MAJOR NEED FOR CONTINUED SUPPORT OF TECHNOLOGY DEVELOPMENT LIES IN THE APPLICATION OF NEW TECHNOLOGIES TO COGENERATION. FURTHER WORK TO ENHANCE THE ATTRACTIVENESS OF WOOD GASIFICATION AND/OR FLUIDIZED BED COMBUSTION WILL BE OF MATERIAL AID IN BRINGING ABOUT A FASTER SHIFT BY INDUSTRIES TO RESPONSIBILITY FOR THE SECURITY OF THEIR OWN ENERGY SUPPLY.

COMMERCIAL AND INDUSTRIAL SCALE ENERGY STORAGE TECHNOLOGIES FOR SPACE CONDITIONING, PROCESS HEAT, AND ELECTRIC GENERATION OFFER GOOD OPPORTUNITIES--FROM SOLAR PONDS TO THERMAL ENERGY STORAGE TANKS TO BATTERIES. I THINK A BASIC OPPORTUNITY IN THE INDUSTRIAL ARENA LIES IN THE CREATION OF WHAT I CALL ENERGY ENTERPRISE ZONES. THESE ZONES, THROUGH VARIOUS TAX INCENTIVES ANALOGOUS TO THE ECONOMIC ENTERPRISE ZONES CURRENTLY BEING CONSIDERED BY THE CONGRESS, COULD ENCOURAGE THE EARLY AND WIDESPREAD USE OF NEW TECHNOLOGIES IN INDUSTRIES WHICH MEET CRITERIA OF HIGH ENERGY INTENSIVENESS FOR THE VALUE ADDED TO THEIR PRODUCT, HIGH EMPLOYMENT, AND AN AGING CAPITAL STOCK FOR ENERGY AND PRODUCTION.

IN GENERAL OUR PRESENT SITUATION IS DRIVING US TOWARDS EXTENSIVE REFURBISHMENT OF THE CAPITAL STOCK OF U.S. INDUSTRY. WE HAVE AN UNPARALLELED OPPORTUNITY HERE TO REGAIN SOME OF THE COMMANDING LEAD WE HAVE LOST BY PROPER ATTENTION TO THE ABILITY OF NEW ENERGY TECHNOLOGIES TO CHANGE THE VERY NATURE OF THE PROCESSES THAT WE USE IN PRODUCING GOODS AND SERVICES. ALTERNATIVE ENERGY TECHNOLOGIES CAN HELP US NOT ONLY DO THINGS WE ARE USED TO DOING BETTER

AND MORE EFFECTIVELY, THEY CAN STIMULATE US TO THE OPPORTUNITIES WE FACE FOR DOING THINGS IN MATERIALLY DIFFERENT WAYS.

IN CONCLUSION, I BELIEVE THE MATURITY OF THE ALTERNATIVE TECHNOLOGY DEVELOPMENT PROCESS SO PAINFULLY CREATED OVER THE LAST FEW YEARS HAS RESULTED IN OUR SEEING SOME TECHNOLOGIES WELL ON THEIR WAY TO BECOMING FORMERLY ALTERNATIVE, AND NEWLY CONVENTIONAL. OUR NATIONAL SECURITY DEMANDS THAT WE PERSIST IN OUR DRIVE TO EXPAND THE AVAILABILITY OF ALTERNATIVE TECHNOLOGIES ON THE BASIS OF SENSIBLE CRITERIA.

I HAVE APPRECIATED THIS CHANCE TO SHARE MY PERSPECTIVE WITH YOU. MY HOPE IS THAT YOU CONTINUE TO SOLICIT INPUT FROM PRACTITIONERS IN THE FIELD. IN PARTICULAR, I WOULD ADD A RECOMMENDATION THAT YOU CONSIDER SCHEDULING A LATER HEARING TO PROVIDE YOU WITH AN EXTERNAL REVIEW AND CRITIQUE OF THE DOE STUDY NOW UNDERWAY ON R & D NEEDS THAT IS BEING UNDERTAKEN AT YOUR INSTIGATION.

the north carolina
ALTERNATIVE
ENERGY
CORPORATION

## The Objectives & Programs of the North Carolina Alternative Energy Corporation

### OVERVIEW

A recent challenge to society has been to find the most appropriate response in a highly changeable and uncertain energy situation. This challenge has existed for a number of years and gives every indication of continuing. North Carolina, in common with the rest of the country, faces the difficult task of balancing our needs and desires for the benefits from energy use with the costs arising from such use. Factors such as the increased difficulty of producing some resources, the consequences of foreign oil supply disruptions, the increasing costs of all energy resources, and the changing environmental, economic and societal costs of energy use all contribute to the complexities we face.

Energy of the right form and price is critical to maintaining and improving our standard of living. We need to develop long-term alternatives that are more efficient and economic than the present ways we produce and use energy resources. Our options already have been expanded by an increasingly varied selection of economical and reliable alternative energy technologies.

Like their more conventional counterparts, each of these technologies is designed to meet a particular need for an energy service. Their adaptability to decentralized use and their capability to be added to our supply capacity at a pace that closely matches demand growth represents a clear advantage when the dangers of either under-building or over-building our energy system are so apparent.

As with conventional energy technologies, alternate technologies are not always economically feasible or appropriate in all areas of the United States. The effects of weather variables, resource availability, and institutional and economic variables, among others, determine feasibility and appropriateness on a site-specific basis.

The uncertainties of our energy future will be buffered by the richness of choices we have in energy because of alternative energy systems. The acceptance by the marketplace of those systems that are technically efficient and economically attractive will be an important ingredient of our energy supply and demand mix. Alternative energy sources will help realize an energy future for North Carolina that is more stable and self reliant.

## THE ALTERNATIVE ENERGY CORPORATION

The State of North Carolina responded to its own particular energy challenge by establishing the North Carolina Alternative Energy Corporation (AEC) to identify, adapt, and promote alternative energy technologies and systems suited to North Carolina requirements. The AEC was established by the North Carolina Utilities Commission in 1980 after a series of public hearings that explored the state's energy situation. The Commission concluded that a state-wide organization was needed to concentrate on solving electricity-related energy problems. The Commission structured the AEC as a quasi-public, non-profit, private corporation and secured financial support for the Corporation from both regulated and nonregulated electric suppliers in North Carolina.

The AEC is specifically charged with (1) finding and implementing alternative energy systems which can moderate the growth of electric demand in North Carolina, and (2) working to shift peak demands for electric power in a cost-effective manner. To accomplish this, the AEC is actively working on both electrical demand reduction systems and alternate energy supply systems.

AEC efforts are divided into industry, buildings, utilities, communities, and agriculture programs. The AEC is developing and adapting a variety of energy efficiency techniques such as conservation, cogeneration and load management. Alternative supply technologies which utilize our wind, wood, and solar resources are among those which offer promise for meeting requirements for heat and power in North Carolina.

The AEC is governed by a Board of Directors composed of both public and utility representatives. The six utility organizations which provide funding for the AEC each appoint a director. These directors represent the state's four investor-owned generation/transmission/distribution utilities (Carolina Power & Light Co., Duke Power Company, Nantahala Power and Light Company, and Virginia Electric & Power Co.), the association of electric cooperatives (North Carolina Electric Membership Corporation), and the association of municipal electric systems (ElectriCities).

The Governor of North Carolina appoints the remaining seven directors, one of whom must be the Chairman of the Board. The public directors presently serving bring a rich variety of experience to the Board. Three public members have backgrounds in industry - textile, agriculture, and solar equipment. Two members serve as faculty at major universities. Two have backgrounds of community service; one as a former state senator, the second with extensive work with local and statewide public interest groups.

The six utility organizations contribute to the AEC in proportion to their kilowatt-hour sales. The AEC operates with an annual budget of approximately $2.0 million which is further supplemented by funds from outside sources where jointly funded projects are attractive.

The AEC structure combines the flexibility and quick response of a private corporation with the public accountability inherent in a quasi-public organization. As such it encourages high levels of cooperation among all major actors in energy within North Carolina. Corporate flexibility allows projects to be implemented that precisely address important issues in order to accelerate widespread application of alternative energy technologies and techniques.

## OBJECTIVES

Valuable improvements in energy use have already been made in North Carolina. Utilities, industries, private citizens, and government have all begun to respond to higher energy prices, to the possible consequences of disrupted energy supplies, and to new technologies and techniques. The AEC is building on the progress made and helping to focus state efforts toward areas of maximum effective impact in the near future. In order to produce the greatest benefit from limited financial and personnel resources, the AEC does not fund work that is too long term, too risky in realizing its outcomes, or too restricted in its usefulness. Projects in which AEC participation would be too small to have any noticeable influence on final results are also unattractive to the Corporation. Instead, the AEC concentrates its efforts on applied research to complete the development and market adoption of alternative energy technologies which will begin to be used in the near term and which will result in significant long-term benefit to electric ratepayers.

In this context, there are six important objectives for the AEC. The first recognizes the importance of promoting a broad understanding that alternative energy systems are credible methods of providing the energy services that we require. The remaining objectives are derived from this basic premise. The second objective addresses the need to increase the energy efficiency of local and state government operations. The third objective recognizes the important role that industrial cogeneration can play in providing economical electrical energy and capacity. Encouraging effective energy investment throughout the residential sector is another objective. The unique nature of the AEC as a focus for projects of common interest and usefulness to the utilities of the state provides the vehicle for carefully designed assistance to help utilities enhance the effectiveness of their own programs in conservation, load management, and alternative technologies. The final Corporation objective is to alert the state promptly to the potential contributions from new energy technologies, systems, and techniques. An expanded description of each objective and a statement of current AEC activity in these areas follow:

### OBJECTIVE I.: Establish the credibility of alternative energy systems in the eyes of consumers and utilities.

This objective has three elements. The first is to develop a methodology and the data that will permit the technical performance, economic cost, and full value of the energy service provided by an alternative system to be convincingly and reliably compared to that of a conventional system. The second element complements the first. Because many alternative energy systems are used in relatively decentralized applications, a detailed understanding of significant future energy use demands is required to identify the most appropriate opportunities for alternative energy systems applications.

Finally, the third element will build on the first two to provide the utilities and the Utilities Commission with the information needed to understand the role that alternative energy systems and programs can play in the state's energy future. For alternative energy systems to be routinely considered in utility planning decisions, the impacts of alternative energy systems on energy demand and capacity needs must be understood. The results will permit comparison of alternative systems against conventional competitors, using the same criteria employed for strategic energy planning by both the state and the utilities.

Meeting this objective will provide the foundation for later AEC activity. Detailed work has begun on the first element. For example, established economic models are being applied using North Carolina utility rates and with the costs and performance of actual residential solar systems. The model calculates the life-cycle cost and value of solar hot water systems compared to conventional domestic hot water service. A methodology for computing the energy-use profiles of buildings is being developed, as well as a preliminary evaluation of super-insulated buildings in North Carolina.

OBJECTIVE II: Assist the operations of state and local government to become fully energy efficient with maximum use of cost-effective renewable resources, load management, and conservation.

Government at all levels has recognized that as electric rates increase, energy consumption by government creates increasing budget pressures. There is growing awareness that budget requirements for energy use in local and state buildings actually displace resources needed to provide basic services to taxpayers. While government has known that technical solutions exist, the available actions which are reasonable and appropriate solutions are only beginning to be implemented.

Government operations will become fully energy efficient only when government itself provides: (a) in-house staff with day-to-day responsibilities for energy management, with substantial training to adequately fulfill these responsibilities, and with time to carry out their assignments; (b) effective means to reduce the risk perceived by city managers, county commissioners and others about spending money in an area as "unfamiliar" as energy; and (c) a commitment on the part of government decision makers to invest in those measures that are clearly cost-effective and in the best interests of the jurisdiction. The AEC, working in concert with other interested agencies, is in a unique position to help accelerate energy improvements in state and local government.

The Corporation has four projects addressing government sector energy supply and demand. They are directed at schools, community colleges, state-owned central steam facilities, and the newer state office buildings.

A cooperative undertaking with the State Board of Education and the Community College system is designed to save up to $9 million per year in energy costs through widespread adoption of load management techniques in public school operations. The project includes development of budgeting procedures for capital investments in load management and assistance to numerous schools and community colleges in developing and implementing load management strategies. Project results will also be valuable for load management applications in other government facilities.

The AEC is carrying out a detailed study of thermal energy storage facilities at schools in Mocksville and Matthews. The systems will provide hot water for space conditioning by heating water with off-peak electricity. These demonstrations will provide good baseline data on the value of similar retrofits to other of the state's many all-electric schools.

The potential for the cogeneration of steam and electricity in the more than thirty state-owned central power plants at hospitals, prisons, and colleges is being investigated. The six most promising will undergo detailed feasibility analyses, with North Carolina State University being the first. Final results will include guidelines for establishing cogeneration facilities to reduce the amount of energy and capacity purchased by the state.

North Carolina law requires energy life-cycle cost analyses to be carried out for all new state buildings of over 40,000 square feet. Work by the AEC will: (1) establish how well existing newer buildings are performing compared to predicted behavior; (2) help ensure that life-cycle analytic techniques used for future buildings are well validated; and (3) integrate the life-cycle analysis into the building design cycle at a point where design decisions will be made in terms of their energy consequences.

OBJECTIVE III: Assist small- and medium-scale industries in implementing the maximum cogeneration that is cost effective for the utility and the industry.

Energy-intensive industries often produce their own steam for process heat applications. Steam of appropriate quality may also be used to cogenerate electricity which can either be used on site or sold to the local utility. In either case, the potential exists for economic advantage to the industry and to its serving utility.

Some of the larger North Carolina industries already have cogeneration facilities in place or are planning them. The utilities are concentrating initially on bringing the larger potential cogenerators on line. Since few small- or medium-scale industries have the necessary expertise in technical or financial aspects of cogeneration to move confidently toward a positive decision, the AEC is helping these industries evaluate and implement cogeneration systems. These systems, while relatively small individually, can collectively provide the generating utility with worthwhile energy and capacity when viewed as an aggregate over their service area.

Provisions of the federal Economic Recovery Tax Act of 1981, when coupled with already existing incentives at the state and federal level, have made cogeneration an attractive option for both utilities and industry. Because of these factors, the AEC recently held a workshop for Chief Executive Officers of those North Carolina industries identified as potential cogenerators. The conference stressed the economic and energy security advantages of cogeneration. Later utility-specific workshops for the same attendees are being developed with utility co-sponsorship to assist industrial progress toward a commitment to invest in cogeneration equipment.

In addition, the Corporation is investigating the potential value of other cogeneration projects in providing technical assistance to cogenerators and in studying financial techniques such as purchase/buy-back agreements, tax-exempt financing, and third-party financing.

OBJECTIVE IV: Encourage economic investments in energy efficiency and alternative resource applications in the low- and moderate-income residential sector

The energy benefits to be realized from residential use of conservation, load management, and alternative suppy technologies are massive. The diversity to be found in the residential arena complicates effective broad-scale approaches. Private and public sector housing, single-family and multi-family units, owner and renter, new and retrofit applications, etc. all present different opportunities and different problems. For ultimate end users, their generating utilities, and ratepayers in general to benefit from potential energy savings and capacity deferrals, adequate information must be provided, societal mechanisms must be developed to implement the right choices in a timely manner, and financial resources must be made available.

In today's economic climate, the limited availability of adequate financing under terms which allow the energy investment to remain attractive to the investor and to the user is the single largest barrier to more rapid and widespread use of alternative energy systems. While innovative financial techniques may be as wide-ranging as creative human imagination can make them, there are, fundamentally, only a few basic concepts. The cost of money may be reduced (this may entail a broad family of techniques ranging from providing interest subsidies to providing guarantees which reduce risk) or the amount of money needed may be reduced (again through a whole range of methods of attracting new investors). With the possibilities for federal assistance being increasingly restricted, the AEC must find mechanisms for reducing interest costs and/or attracting new investors. Moreover, the AEC must focus on actions that will be brought about in the normal marketplace rather than on actions for which the AEC or others would be expected to assume an on-going subsidy role.

The AEC has begun many activities aimed at moving residential decision makers toward increasing energy efficiency. These projects, like all other AEC work, require careful attention to taking advantage of, and not duplicating, previous work of others in North Carolina and elsewhere. A sampling of these projects include:

- the Governor's Showcase of Solar Homes is a joint project with the state Energy Division. By the end of 1982, most of the people in North Carolina will have had the opportunity to tour new and older homes in their area that have been opened to the public for two weekends to show the variety of solar systems that are possible - from low cost, do-it-yourself greenhouses and solar collectors to the most sophisticated active and passive systems.

- a joint project with the State Board of Education is aimed at making solar homes the kind of homes routinely built as a part of vocational training programs in high schools and community colleges. In the course of this project, not only will students and teachers be trained in solar techniques, but also local architects and skilled craftsmen will become familiar with the advantages of solar and energy efficient home construction.

- the City of Wilson is demonstrating innovative ways to encourage energy conservation within its utility service area. This project has the support of the state-wide ElectriCities organization. It includes the targeting of low-income neighborhoods for home energy conservation workshops stressing do-it-yourself techniques.

- the Rural Advancement Fund near Charlotte has trained its paraprofessionals in energy conservation techniques they can deliver to the low-income families they serve. The Agricultural Extension staff from North Carolina A&T University had their paraprofessionals in the same training, and may conduct a similar program later.

- at the 1981 State Fair the AEC and the Energy Division sponsored the "House Power" dome. The displays concentrated on showing fairgoers how they as individuals can effectively assume significant responsibility for their own energy future.

- the potential usefulness of specific financial techniques is being explored. Joint Housing Finance Agency/utility partnerships, municipal solar utilities, shared savings and equipment leasing, multi-family retrofit escrow projects, Electric Membership Cooperative loan programs, and utility-funded financing for low-income citizens are all being studied for their appropriateness in North Carolina.

- the AEC is sponsoring preparation of a sourcebook on alternative energy to be used by the state's 100,000 4-H Club members for their major focus of the year.

OBJECTIVE V: Assist investor-owned and public utilities to enhance the effectiveness of their conservation, load management, and alternative technologies programs

The utilities of North Carolina already have major programs in areas that complement AEC objectives. Clearly, no purpose is served by AEC efforts to duplicate what already exists. There are good opportunities, however, for AEC projects of two kinds. The first is based on the AEC providing a common focal point to study the separate experiences of individual utilities which have implemented similar programs. Results will, for example, identify successful approaches to a problem by one utility that will be useful in another service area. The second type of project recognizes the usefulness of the AEC facilitating the exploration of new energy systems and techniques of common interest to many North Carolina generating and distributing utilities. Projects of either type obviously require extensive coordination with, and participation by, the state's utilities as each project is designed and carried forward. Implementing the results will be the exclusive province and responsibility of member utilities. Projects underway now are:

- development of recommendations for even more effective load management marketing strategies. Results will be based on customer surveys of market penetration rates by sector, importance of incentives, etc.

- development of load management program recommendations for utilities serving primarily a distributing, rather than generating, role. The project will concentrate on the Electric Membership Cooperative system, with ElectriCities and major generating utility staff as participants to ensure maximum relevance to their systems. The project will analyze demand profiles, state-of-the-art load management technologies, ways of ensuring that load management policies are beneficial to all parties, and the range of financing mechanisms that can be used.

OBJECTIVE VI: Provide reconnaissance and evaluation of alternative energy resources/technologies/techniques

The AEC has a responsibility to ensure that the state misses no opportunity to take early advantage of the best of recent developments. A number of projects currently fall in this category:

- a project qualitatively assessed the potential for central-station scale wind turbine installations in the state. The study confirmed that the best potential lies in the western mountains and along the coast. More detailed wind resource analysis is needed to determine if where, how often, and how hard the wind blows will provide an attractive energy and capacity resource to the utilities.

- other projects have begun to analyze how best to utilize heat pumps in private homes, how to move residential and commercial air conditioner loads off peak, and how well small brick thermal energy storage devices would be accepted by consumers in the mountains. Another project is evaluating the technical and community potential for micro-hydro electric generation in western North Carolina.

- A major effort in the agricultural area, with North Carolina State University as contractor, will develop detailed farm energy audits. The three major agricultural sectors of tobacco, poultry, and swine are being evaluated in three counties to determine the actual state of on-farm energy consumption, and the potential for alternative technology, conservation, and load management applications. In the poultry area, the work will include evaluating energy options up the production chain of this vertically integrated industry.

Mr. **Heitowit**. Thank you, Dr. Veigel.

We will now go to a brief question period. My colleagues have been following your testimony, and taking notes. I am sure we have many questions.

I will go first to Dr. Frankel. Gene?

Mr. **Frankel**. Thank you.

Jon, you were at the Solar Energy Research Institute for a number of years. I wonder what your thoughts are on how we should think about the role of that institution in serving the RD&D needs for renewable energy? The administration has proposed to make it a purely research organization just doing basic research in areas like photovoltaics and bioconversion.

Mr. **Veigel**. Basically, I have very mixed emotions. I am pleased that SERI continues in its very necessary basic research role and I am immeasurably saddened by the loss of what I consider to be the opportunity to have turned that institute into a renewable energy institute at which both the research and the commercial aspects of all renewable technologies could have been carried out in one place and integrated there.

Mr. **Frankel**. Almost all of you talk in terms of near-term commercial development and yet those are dirty words to this administration. I wonder if you would like to comment on what you think are the appropriate stages in the technology development process, starting with basic research and going through development and demonstration, for Government to involvement. Should we take it all the way to commercialization as the Carter administration wanted or back-off at applied research as Reagan wants to, or find some compromise in the middle ground.

Mr. **Block**. We cannot hear you.

Mr. **Frankel**. All of your statements imply the rejection of the administration's contention that Federal RD&D should be limited to basic research. If that is the case, how far should we take the process that starts with basic research, and ends with commercialization. Where does the Government involvement break off? What recommendations would you make to us for criteria for determining when Federal involvement should end?

Mr. **Lumsdaine**. As I understand the question, I think there should be a parallel effort in long-term research and also short-term development work, because there are a lot of technologies right now that are nearly mature that can go out with some Government support, for example, as I said before, in the low technology kind of area where industry is not particularly interested in taking over because of low profit margins and that sort of thing. But there should be long-term research in R&D into areas like photovoltaics, where I think there is a lot of work that still needs to be done. In other fields, long-term research should continue, but the most pressing needs are the ones that I have outlined for the next 10 years in terms of short-term research and cogeneration.

Mr. **Block**. I agree with what Dr. Lunsdine has said. The question you ask is a relatively difficult question to answer. For example, solar hot water heating is a technology that is in the marketplace, but still in need of R&D, as is the case of nuclear powerplants. They have been in the marketplace many years, but we are still doing tremendous amounts of R&D on nuclear technology.

I personally believe that when the industry becomes strong enough, it will be able to handle its R&D problems and other Governmental support will automatically phase itself out. I do not believe we are at this stage now with solar energy.

Mr. **Veigel**. I have very little to add to that. I have some hesitation to answer at all because I think what we really need is not only the staff from your committee, but from two or three other committees in the Congress in total. That aggregation represents the audience that we really need to be addressing this issue with.

I support the administration in asserting we have too long overlooked the discipline that the market can introduce into these questions. The unfortunate aspect is the current administration policy, while it enforces this discipline, it is simultaneously going to manage to smother the very real enthusiasm that exists out there and, in fact, be totally counterproductive in almost insuring that some of these technologies will not be able to be appropriately considered by the private sector and the correct decisions made.

We are going to persist in some of our old decisions and habit patterns which are totally counterproductive.

Mr. **Frankel**. Pursuing that a little bit further, you all cited problems with the demonstration projects that were run by the Department of Energy, especially the solar heating and cooling and industrial process demonstrations. Assuming we are going to continue the demonstration activity, how can we avoid such problems in the future?

Mr. **Lumsdaine**. Well, I think this can be done by planning and having a good national policy and conducting these demonstration projects with good homework, including the types of equipment that will be used in the field. We must make sure that quality assurance is there before these are put out in the field and we must make sure there are trained manpower because time and again there were people that were not trained who put these things together and made many, many mistakes, even when the equipment is fairly good. Installation by trained manpower is very important.

Also, I think we have seen a lot of premature demonstration in solar technology. Premature demonstration has really damaged the solar crediblity quite a bit.

Mr. **Veigel**. My response is that I think you as a staff need to have the strength of will to restrain the romantic enthusiasm of single technology proponents, and hopefully avoid building something because its only advantage is that it will be in some member's district.

Mr. **Block**. I would like to comment briefly on demonstrations. I believe there should not be any demonstrations as they are currently defined Demonstrations by my definition are experiments to obtain performance, operation and maintenance information. If we do not get performance, operation and maintence information on demonstrations, then we are not doing the job that we should be doing.

Mr. **Frankel**. One last question.

Mr. Block, you talked about the number of companies pulling out of the solar area. The administration again has claimed that the private sector is going to pick up the work being done by the Department of Energy, yet we have been hearing indications that in fact the private sector is matching the DOE cutbacks.

I wonder if any of you have any systematic reading on what the private sector response has been on the cutback?

Mr. BLOCK. My experience has shown that private industry does not do any R&D, except what is profitable for them. I hate to use this example, but certainly the recent synthetic fuels pullout by Exxon, our largest Fortune 500 company, illustrates the point that profit is the determining factor. A company's profit motive and its R&D program are not necessarily synonymous.

Mr. VEIGEL. If I could go back and pick up and comment on one of your earlier questions, which I think you asked about the appropriate State role. One of the pleasures of my job in North Carolina is discovering that one thing we can do that seems to accelerate the process more than almost anything is to lower the apparent transaction cost to all the parties involved.

Our interest is not one of profit and we are not a government agency, so we can be viewed with some credibility by the people out there. We are finding that we can be a marriage broker. We are dickering with some out-of-State investors now to bring in a couple of hundred million dollars for investment and cogeneration facilities. It is that role in catalyzing actions that might otherwise have taken place but at a rate that is not sufficient for our national purposes where I think the State can play a very critical future role, and where I think more attention needs to be paid by the Federal Government to our doing that.

Mr. FRANKEL. Let me ask you a followup to that. Does it help also that you are a corporation rather than a State agency and might we also think about something like that on the Federal level?

Mr. VEIGEL. Absolutely. We are quasi-public and quasi-private, depending on which side of the fence you view us from. That we are a corporation can not be overstressed as an important adjunct to our ability to succeed.

Mr. HEITOWIT. We will go to Dan Steinway, who has some questions.

Mr. STEINWAY. Thank you, Ezra.

In testimony before our committee on numerous occasions, the administration has pointed out that tax incentives have played a significant role in the development of renewable energy resources.

Do you agree with their views on the effectiveness of tax credits, and what do you think would be the response of the private sector if these tax credits were extended to, say, the year 1990?

I would like to address the question to all three of the witnesses and hear your response.

Mr. LUMSDAINE. Well, tax credits are crucial in certain areas in terms of the renewable technologies, but they can have also a negative effect. For example, the Australian Solarhart solar water heater which is a thermosyphon system that is sold in Australia for 800 Australian dollars—which is about $1,000—when transported to San Diego, sells for about $2,400.

Now, the transportation costs and some minor changes would not increase the costs that much. But, as you know, California has a tax credit of 55 percent. I think the implication is clear. Sometimes tax credits can be counterproductive, yet, in certain areas, they can be critical.

For example, in the case of passive solar, only very recently has the administration recognized passive as being something that is useful. It has recognized active systems in the past, but not passive systems. So tax credits could be useful in certain areas.

Mr. VEIGEL. I think that tax credits are effective depending on the sector in which they are used. They are essential in the residential area if for no other reason than the demonstration that the Federal Government gives its stamp of approval to these things by having them.

I think, however, in contrast, the usefulness of energy specific tax credits in the industrial, commercial or utility arena is much overplayed. It may turn out the administration in fact has inadvertently done the most it will ever do for alternative energy resources in the tax provisions of the Economic Recovery Tax Act of 1981. The provisions of this act were not designed for energy purposes but they are certainly serving that purpose in enabling us to convince people that these things are economically sensible choices for them to make.

The presence or absence of a 10 percent investment tax credit is icing on the cake. The body of the cake is the accelerated depreciation, the availability of third party leasing arrangements, project financing, et cetera.

Mr. BLOCK. I strongly support the tax credits and feel that the solar industry requires tax credits in order to have the additional bit of stability which will be critical in strengthing the industry. I think in time, once the industry gains its strength, credits should be repealed. I do not foresee this event happening by 1985.

Credit should be extended.

Mr. STEINWAY. As a follow-up question to my first question, Jon, you alluded to the President's economic tax package that was passed last year. In that package, they include an R&D tax credit specifically geared to the private sector for increased R&D.

Do you beieve this R&D tax credit will play a significant role in renewable energy development?

Mr. VEIGEL. I think it is playing a reasonably significant role not only in renewables but even in conservation. There are some firms that have been established to provide conservation retrofit services for homes where their initial financing is based on the availability of that R&D tax allowance.

So I think it is important but I think it is kind of hidden beneath a basket now insofar as the visibility of it is concerned.

Mr. STEINWAY. Dr. Block, do you have any comments?

Mr. BLOCK. No, I agree with what Jon says.

Mr. STEINWAY. I would just like to ask one final question in the R&D area relative to sitmulating the development of renewable energy resources, and it deals with the PURPA legislation. Under the PURPA legislation, utilities are required to purchase electricity from small power producers, including alternative energy developers, at the utilities avoided cost.

Do you believe that provision, as a regulatory incentive, will play a significant role in simulating the development of alternative energy resources?

Mr. VEIGEL. I think it depends on the State. Some States like North Carolina have legislation of their own so that even without PURPA, we could proceed. But I think too much concentration on PURPA hides the fact that while important, it is by no means sufficient and there are other ways of doing the same things more effectively and quicker.

What we really need to do is establish some kind of policy so that it is to the benefit both of the producer of the energy and the purchaser of that energy, the local utility, to enter into contracts.

We are through PURPA, perhaps, making it possible for the utility to be a larger coowner of joint facilities and addressing the issue of wheeling of power, interconnection costs, and making it just more feasible for the utility and the industry to do the negotiation they need to do.

I am also finding that one of the roles we can serve is to perhaps set up what I am calling cogeneration cooperatives, where what we do is we aggregate the load and the capacity from a number of small industries and that can be made available for purchase by the utilities so that they do not have to do individual negotiation with a large number of 1 and 2 megawatt sources and/or to use that cooperative as an aggregated source of funding.

No investment house is interested in coming in and funding a $1 to $2 to $10 million project, but if you present them with 50 to 100 megawatts costing $100 to $150 million, and you say we will lower your transaction costs because we will do the technology evaluation for you, their eyes start lighting up because that is a way of making things happen where it otherwise would not happen.

Mr. STEINWAY. Thank you very much.

Mr. HEITOWIT. Does Dr. Hanson have any questions?

Mr. HANSON. Mr. Fuqua has indicated a number of times that he believes, that we need to develop all sources of energy, and this generalization could prove useful and helpful to important segments of our effort.

But the criticism has been made that this leads to a diffuse effort with consequent wastes. The administration now, by cutting back so much, says "let it be decided in the marketplace."

What I would like to ask of anyone that choses to respond is, do you think that Congress has been sufficiently discriminatory in its support for energy R&D, and if you agree with that, then how would you propose that Congress might sharpen its focus in dealing with this problem?

Mr. BLOCK. Congress has obviously been discriminatory in its support of different programs by the different levels of funding. I believe that the level of funding from Congress is the discretionary item that you are speaking of.

Then the next question is, what happens if you reduce the funding way down, to zero? This case is where the problem occurs. I believe that we should not reduce programs to zero. We should try to maintain a very low level in all programs in order to give the marketplace a chance.

I am very afraid that the zero funding level is a signal that the technology is bad—a wrong signal.

Mr. VEIGEL. Initially I think it was appropriate for the Congress to have a shotgun approach to technologies. We really did not know which were the better ones, which ones were going to work and which ones were not going to work.

But that is something I do not think we can either afford in terms of energy or the economy now. I think we need to be more discriminatory. I would be very disappointed if what I saw in the Congress was a commitment to the shotgun approach, because that would seem to me to be the same kind of a technique followed by somebody whose only tool is a hammer, and then all problems start looking like nails.

If all you do is support everything you supported in the past because you have supported it in the past, that is insufficient rationale for it. The mechanisms to make those choices were the same as I outlined in my paper here. We have all got to pay more attention to the use to which that technology is going to be put, and compared to those things with which it is going to be competing and make our choices.

Mr. LUMSDAINE. Well, I agree that in the past there has been a shotgun approach in terms of going into all different types of renewable technologies, but now I think there are only 3 or 4 that warrant strong support.

Photovoltaics, for example, we found is extremely important, biomass and in certain cases also passive solar that require continual Government support.

Mr. HEITOWIT. Jack Dugan.

Mr. DUGAN. Dr. Lumsdaine, I would like a clarification of your statement on page 11 where you say:

> Especially in times of tight budgetary constraints it is necessary that R&D support for short-term renewable energy projects continue at an adequate level, even at the cost of having to reduce funding for long-term, high technology projects.

First of all, I think it is very difficult for the members of the committee in this budget climate to defend short-term projects versus long-term projects in renewables.

But secondly, I was curious as to whether this would be consistent with an application of Dr. Veigel's criteria to test what technologies are worth funding toward the marketplace.

Could you clarify that for me?

Mr. LUMSDAINE. Well, I think it is consistent. In fact, some of the recommendations that I have are consistent with a report that recently came out in October 1981 by the Energy Research and Administrative Board set up by the then Deputy Secretary of Energy. A lot of their recommendations are nearly the same as mine, and I did not have the benefit of that report until I finished my written testimony.

Mr. DUGAN. That was the ERABB?

Mr. LUMSDAINE. Yes, sir. In fact, I was surprised to find out that they are almost the same types of recommendations. So it is very consistent with what Dr. Jon Veigel is saying.

Mr. DUGAN. Do you think, though, realistically, that that is easily accomplished by the legislative body in this kind of climate with a tremendous pressure, not only in the funding levels but the philosophy of the Government role that is high risk, long term? I just do not see how it is very defensible in that kind of climate. Our members have enough of a problem, I think, making sure there is additional money for renewable resources, but if you give them this kind of a slant. I think it makes it much tougher for them to make sure there is enough money to go around in the right directions.

I just find it difficult.

Mr. LUMSDAINE. Well, I apologize for that, but I wrote exactly how I felt and from my 20 years of experience in alternative energy and solar energy, this is the way I see it.

I understand that in this present climate, this is going to be tough. This is exactly the sort of thing that is not being looked on with favor at the present time, but this is also the sort of thing that needs to be done for the benefit of the American people.

Mr. DUGAN. Thank you.

Mr. HEITOWIT. Well, I want to thank all three of you gentlemen for very thoughtful and frank statements. You have been very helpful to us.

I would like to mention that Dr. Lambert has invited all of the participants in the hearing, both the witnesses and the staff, to be his guests at lunch. We will be departing from this location, the Western Plaza of the U.S. Pavilion, at approximately 12 noon to go over to lunch at another location. We will have guides to take us over, so if you can join us, we certainly would appreciate it. Thank you very much.

Mr. HEITOWIT. We are now ready for our second panel this morning and we are pleased to invite Mr. Dave Christensen, manager of alternate energy programs for Wyle Laboratories in Huntsville, Ala.; Dr. Robert Cassanova, associate director of the energy and materials sciences lab at Georgia Tech; and Dr. Charles G. Groat, who is with the Louisiana Geological Survey in Baton Rouge, La.

Gentleman, your full statements will be entered in their entirety and if your presentations could be roughly 10 minutes, that will give us full time for some questions before we break for lunch.

We are going to start with Mr. Christensen.

## STATEMENTS OF DAVE CHRISTENSEN, MANAGER, WYLE LABORATORIES, HUNTSVILLE, ALA.; ROBERT CASSANOVA, ASSOCIATE DIRECTOR, ENERGY AND MATERIALS SCIENCES LABORATORY, GEORGIA TECH EES, ATLANTA, GA.; AND CHARLES G. GROAT, LOUISIANA GEOLOGICAL SURVEY, BATON ROUGE, LA.

Mr. CHRISTENSEN. Thank you, Mr. Chairman, members of the committee.

I am Dave Christensen, manager of alternate energy systems for Wyle Labs, a test corporation founded in 1949. We currently employ about 2,200 people and provide technical services and support to the energy, aerospace, transportation, and electronic sectors.

Over $20 million in funding is received and applied to the support of energy programs by Wyle out of total sales of $250 million last year. This support included renewable, fossil, and nuclear program activities.

I am pleased to appear before you today in this unique setting to discuss my views and provide information related to research, development, and demonstration needs for renewable energy over the next several years. This forum is needed and I wish you every success in meeting the objectives and goals of the committee and Congress for continuing Federal support of renewable energy technology.

I would also like to add that my position certainly reinforces some of the previous statements of the panel members and I will try to keep my remarks brief.

To help determine those renewable energy technologies and related research, development, and demonstration activities which are still needed, a composite listing of ideas was developed and incoporated to my written statement. Please refer to it for details. To conserve time, I will not recap the detailed recommendations.

In addition, a number of common needs for RD&D are included to indicate areas which might provide benefits to more than one of the renewable energy technologies.

Considerations for the proper role of the Federal Government in RD&D programs are also listed for your possible use in these hearings.

The challenges of higher energy costs, interruptions of supplies and periods for deployment and operation of powerplants are being addressed by the broader use of energy conservation practices and applications of renewable energy resource and technologies.

Particularly at the grassroots and small business levels there is a prevailing spirit of innovation and competition. Likewise, international interest in renewable energy is soaring as locally available energy resources are being recognized for their premium quality and value.

The worldwide interest in solar and wind energy conversion, broader use of feedstock available from plant materials and wastes, and energy conservation is reflected by the large number of new products now becoming available. Manufacturers are producing a large variety of components and systems and providing numerous technical services to help insure that renewable energy resources are used to meet an increasing share of overall energy needs.

All in all, the United States has undertaken one of the most intensive, widespread renewable energy programs in the world. These major efforts by government and industry contribute to economic and social advancement by reducing energy related problems and smoothing the transition from depletable petroleum-based fuels to clean renewable energies. Hundreds of millions of dollars have been invested by the American public and industry to advance the state-of-the-art of solar and other renewable energies and to improve energy conservation methods. The results are impressive.

Much of the credit for the status and vitality of the U.S. renewable energy industry is a result of the extensive research, development and demonstration programs implemented by the Department of Energy. Although general economic conditions and high interest rates have dampened even more rapid growth of this young industry, it is dynamic and its annual sales are steadily increasing. However, there are many recognized areas needing additional technical advancement and support, if the full potential of renewable energy resources are to be realized.

We need to strongly consider bringing worthwhile Federal programs to their logical conclusion and make the relatively small investments now needed to properly evaluate performance, to quantify and disseminate results, and to make key improvements, where warranted, to insure the given technology has been given a proper appraisal.

Well-planned laboratory, field testing, and pilot plant operations are still necessary as well as incremental improvements of components and subsystems, and the exploration of new and advanced concepts, including hybrid and combined systems.

The wide variations in the complexity and development paths of each of the renewable energy technologies will also necessitate more flexible management programs and improved methods to compare their relative merits, and to establish their R&D investment needs and potential contributions for meeting our future energy needs.

Detailed examples of research and development areas of prime interest are included in the written statement to signify particular needs of the various renewable energy technologies. This listing was developed through assessment of current literature and direct contact with a number of individuals involved in renewable energy technology. It includes the following categories: Passive solar heating and cooling; active solar heating and cooling; photovoltaic energy conversion; solar thermal power conversion; wind energy conversion, ocean thermal energy conversion, hydropower, organic or biomass conversion, geothermal; and satellite power stations.

Priorities are urgently needed to establish the relative payoff value of the renewable energy technologies and their respective research and development requirements. A modest amount of funding, carefully placed to further stimulate a proven technology might have a much greater value than the same funds added to a longer term high-risk bet that might never reach maturity. A balanced program is needed to assess each technology from an equitable standpoint and rank the estimated return on Federal investments according to the expected energy contributions possible. This is a difficult task but system analysis techniques and methodologies are available, and a comprehensive and coordinated effort should be implemented to accomplish this task. In any event, a balanced and realistic program is needed to efficiently use available Government funds.

There are a number of common needs that become apparent when reviewing research, development and demonstration requirements for the renewable energy technologies. Obviously the need for more reliable and efficient equipment and lower costs recurs repeatedly, especially since the diffuse and low density nature of solar and wind resources mandates the use of large areas of equipment. And not only the technical problems are in need of attention. Quality demonstrations, large production incentives and improved financial and capitalization methods are likewise in obvious need of support. There are many areas where Government assistance would benefit more than one technology and the youthful industry at large. These should be carefully identified and given higher priorities for funding support.

The following types of commonly needed R&D efforts are included in the written statement: materials research, fluids research, improvement in conversion processes, improvements in all types of energy storage systems and power conditioning equipment (this was given a high priority by many of the people I talked to), failure modes analysis; support of advanced concepts and innovative designs; improvements in controls and diagnostic instrumentation; continued deployment of well designed, well placed, and carefully monitored demonstration, and proof-of-concept systems; improvements in heat transfer equipment; attempt to realize overall reductions in costs; additional assessments of financial and investment incentives; long-term evaluation of operational, maintenance, and reliability data; continuing support for resource and siting assessments, continuing support for export assistance and overseas demonstrations of quality systems and hardware; expanded support of long-term data collection, monitoring, test and analysis of all technologies; and develop planning, asssessment, and methodology tools to compare and select optimum technology and design for various applications.

I would particularly like to address the need for additional monitoring and testing to refine and improve the level of performance and reliability already achieved and to validate and verify the relative merits of each renewable technology. Testing activities encompass a broad range of technical expertise and applied skills to properly assess and evaluate renewable energy equipment. They include a number of support program elements as listed in the written statement.

Broadly supported testing efforts as well as consensus test standards are vitally needed by the equipment manufacturers and users to allow comparison, rankings and improvements to evolve.

For example, aircraft are flight tested today under Government sponsorship although they have been in development for almost a century. So should large power towers, windmills, and other new systems be operated and tested over long periods of time to allow their full development and assessment. Again, Government support and sponsorship is vitally needed to retain the momentum already established and to allow full exploitation of these promising technologies.

A team effort of Government and private test laboratories, manufacturers, utilities and other users is essential at this stage to properly assess critical RD&D programs. Without key funding support from Federal resources to complete the operational test programs and to feed the results back into the R&D priorities, a huge public investment may be wasted and needed technologies may be restrained from reaching their early maturity.

Gentlemen, because of time I won't read the list of specific recommendations, for the Government programs. We have already heard some of these this morning, so I will now summarize my statement.

Independent test laboratories, such as Wyle, play a vital role in the research, development, and commercialization of renewable energy equipment. We have made extensive capital investments in specialized test facilities such as a large solar simulator, environmental test chambers used for photovoltaic modules, and systems test equipment used for solar water heaters. Private organizations are willing to invest their own money to meet the R&D needs of Government and industry when long-term commitments of interest and support are evident. Thus, private capital can be applied to relieve the need for Government spending in this area.

As service oriented organizations, in close cooperation with Government laboratories, private test laboratories provide unbiased evaluations of experimental and other equipment available for operational use. This can provide the manufacturer and the user with the performance and reliability data needed for making product improvements or for equipment selection and use.

At this point in the advancement of renewable energy technologies, clear directions and long-term commitments for sustained programs are needed to support capital investment decisions. The industrial community looks to the Government for leadership and selection of priorities for renewable energy research and development, that could provide a more secure energy base in the future.

This is particularly true in those areas having high risk and long-term periods before payoff. Both technical and nontechnical aspects must be carefully considered and detailed planning efforts performed to select needed programs and activities.

The renewable energy technologies as a group merit a position of strong interest and support. They offer many advantages for allowing energy independence, providing cleanly derived power, enhancing domestic employment and expanding our industrial and municipal bases. Industry is quite willing to invest in developing these valuable resources and will quickly respond to the stimulation of selected areas as indicated by Government research and development support on a sustained basis.

Government programs should not discourage private investment and interest in the renewable energy technologies by reducing research, development, and demonstration spending. A balanced, long-term, and continuing effort is needed to give new technologies a fair chance to support the transition from using depletable fuels, over to the widespread use of clean, safe, and readily available domestic resources.

In conclusion, the need for alternative domestic energy supplies has not subsided. It is as pronounced, if not more so, today as in the decade of the seventies. The technical capacity to meet that need has also endured admirably. For example, the vast reduction in the cost of photovoltaic hardware, over a relatively brief period, underscores the significant potential for technology advancements and contributions from the government/industrial/university team.

During the eighties this potential must be further developed. It will require our concerted efforts and can result in the further evolution of necessary energy resources. Let there be no mistaking the fact: widespread use of energy and power from renewable resources is an attainable reality.

This concludes my testimony, Mr. Chairman. I thank the committee for this opportunity to appear here today and I will be pleased to answer any questions. Thank you.

[The prepared stratement of Mr. Christensen follows:]

## PREPARED STATEMENT OF DAVID L. CHRISTENSEN, MANAGER, ALTERNATE ENERGY PROGRAMS, WYLE LABORATORIES

### INTRODUCTION

This statement is submitted to provide information related to the research, development and demonstration needs for federal support of renewable energy technologies over the next several years. It is submitted by Wyle Laboratories, one of the largest independent R&D and testing laboratories in the world for presentation at a Field Hearing on May 28, 1982, as requested by the U. S. House of Representatives, Committee on Science and Technology, Energy Development and Applications Subcommittee. Wyle Laboratories, established in 1949, provides technical support and services to energy, aerospace, transportation and electronic organizations and industries. Corporate sales for fiscal year 1981 were 253 million dollars with a current employment level of 2,200 personnel.

The research, engineering and testing operations provided for renewable, nuclear, and fossil energy programs represent some 60% of the activities of the Wyle Scientific Services and Systems Group and over 8% of the total corporate efforts (over $20 million per year in support of energy programs). Clients for renewable energy programs include government organizations such as NASA, JPL, DOE, SERI, Sandia, NBS, TVA and state energy offices. Intensive test and evaluation efforts have been provided by Wyle in support of the National Solar Heating and Cooling Demonstration Program for commercial and industrial applications. Support of the Solar for Federal Buildings Program now includes acceptance testing activities at sites across the country. Other government related programs for test method development, photovoltaic modules and power conditioning analysis, and environmental testing are now in process.

Wyle has a vital interest in the continuation of the needed research, development and demonstration programs and is actively supporting the efforts of industrial organizations to qualify, certify, and improve their renewable energy equipment to meet the operational requirements of the marketplace. Some 250 individual solar collector and solar water heater systems tests have been performed for over 100 different industrial organizations. Test and evaluation support is provided to manufacturers of photovoltaic modules, storage units, and biomass conversion systems. Also, a large steady-state solar simulator has been developed for in-house use and similar facilities have been delivered to support the test programs of clients.

To help determine those renewable energy technologies and related research, development and demonstration (RD&D) activities which are still needed, a composite listing of ideas was developed for incorporation into this statement. This information was compiled with the assistance of co-workers at Wyle and other knowledgeable individuals from industrial, institutional and governmental organizations. Their support is greatly appreciated. In addition, a number of common needs for RD&D are included to indicate areas which might provide benefits to more than one of the renewable energy technologies. Considerations for the proper role of the federal government in RD&D programs are also included in this statement.

## TECHNOLOGY ASSESSMENT

The challenges of higher energy costs, interruptions in supplies, and the longer periods required for deployment and operation of power plants are being addressed by the broader use of energy conservation practices and application of renewable energy resources and technologies. Particularly at the grass roots and small business levels, there is a prevailing spirit of innovation and competition. Likewise, international interest in renewable energy is soaring as locally available energy resources are becoming recognized for their premium quality and value.

The worldwide interest in solar and wind energy conversion, broader use of feedstock available from plant materials and wastes, and energy conservation is reflected by the large number of new products now becoming available. Manufacturers are producing a large variety of components and systems and providing numerous technical services to help ensure that renewable energy resources are used to meet an increasing share of overall energy needs.

The use of solar energy for generation of hot air, hot water, steam, and heating other working fluids has been widely demonstrated. A viable industry, comprising designers, component manufacturers, test facilities, system packagers and installers, and marketing organizations has been established. These relatively simple systems are easy to ship and install, and have broad applications for providing climate control in buildings, improving heat-pump operations, and enhancing agricultural and commercial processes.

Industrial products and services to help heat and cool buildings through passive and natural-energy flows are also available. These include shades, shutters, and screens, thermal energy-storage devices, and greenhouse additions. These products can make major contributions toward reducing energy consumptions in buildings.

High temperature solar conversion systems, which use concentrating surfaces and tracking to focus direct sunlight, are now being produced and marketed. These systems include optical lenses, parabolic dishes, and troughs for producing such products as industrial steam. Thermal or electric power can be provided quickly and cleanly in areas where power is not available, or is very costly, and where sufficient direct sunlight is available.

Wood, man's oldest fuel, is being evaluated and more widely used. The U.S. pulp and paper industry now produces half of its power by burning available wood wastes. Homeowners save money by using wood burning stoves, and utilities are studying plans to generate electricity by using wood instead of coal. With little government support, wood burning now produces more delivered energy than the nuclear plants in this country. Conversion equipment for a variety of organic or plant materials is available, which can provide oil, heat, steam, alcohol, electricity, methane, and other fuels. Many new types of crops and feedstocks are now being considered in order to expand the available resources of solid, liquid, or gaseous biomass-derived fuels.

Wind energy has been used for centuries in all parts of the world. American manufacturers are bringing the prices of wind machinery down and improving its reliability and efficiency. In the United States, large wind conversion units to provide electrical power in conjunction with electrical grids are being demonstrated. Smaller wind power generators are available for rural areas.

Solar arrays using photovoltaic solar cell devices that convert sunlight directly into electricity now produce power ranging from a few tens of watts to many kilowatts. Cost-reduction goals are being met, and by continuing research and development efforts, it is expected that the cost for grid-connected power will be competitive in five years, with costs of electricity generated by using petroleum products. These systems are particularly adaptable to providing power to remote areas where conventional electric power is not available or is extremely expensive. In many cases, they are now cost competitive and being used for these remote site applications.

Design and engineering firms, test laboratories, and technical service organizations are available to provide needed support for most types of renewable energy projects. Specialized teams are involved in expanding the application of energy conversion and utilization equipment based upon locally available solar energy resources.

All in all, the United States has undertaken one of the most intensive, wide-spread renewable energy programs in the world. These major efforts by government and industry contribute to economic and social advancement by reducing energy related problems and smoothing the transition from depletable petroleum-based fuels to clean renewable energies. Hundreds of millions of dollars have been invested by the American public and industry to advance the state-of-the-art of solar and other renewable energies and to improve energy conservation methods. The results are impressive.

Much of the credit for the status and vitality of the U. S. renewable energy industry is a result of the extensive research, development and demonstration programs implemented by the Department of Energy. Although general economic conditions and high interest rates have dampened even more rapid growth of this young industry, it is dynamic and its annual sales are steadily increasing. However, there are many recognized areas needing additional technical advancement and support, if the full potential of renewable energy resources are to be realized.

We need to strongly consider bringing worthwhile federal programs to their logical conclusion and make the relatively small investments now needed to properly evaluate performance, to quantify and disseminate results, and to make key improvements, where warranted, to insure the given technology has been given a proper appraisal. Well planned laboratory, field testing, and pilot plant operations are still necessary as well as incremental improvements of components and subsystems, and the exploration of new and advanced concepts, including hybrid and combined systems.

The wide variations in the complexity and development paths of each of the renewable energy technologies will also necessitate more flexible management programs and improved methods to compare their relative merits, and to establish their R&D investment needs and potential contributions for meeting our future energy needs.

## SELECTED RESEARCH AND DEVELOPMENT NEEDS

Examples of research and development areas of prime interest are listed below to signify particular needs of the various renewable energy technologies. This listing was developed through assessment of current literature and direct contact with a number of individuals involved in renewable energy technology.

### Passive Solar Heating and Cooling

- Improved storage materials, insulation methods, and shading devices
- Advancement of daylighting techniques to reduce electrical lighting use
- Improved instrumentation, test methods, and evaluations of operational results
- Improved cooling and dehumidification techniques

### Active Solar Heating and Cooling

- Need for additional testing and long-term assessments
- Improved packaging and system design integration
- Improvements in hot and cold storage systems, stratification methods, control strategies, and load matching
- Improved integration with conventional HVAC systems and retrofit flexibility
- Advancements in cooling technology to raise efficiency and lower costs
- More uniform codes, standards, testing, rating and certification procedures

### Photovoltaic Energy Conversion

- Need for higher efficiencies, particularly at the array and system levels
- Advanced manufacturing methods and lower costs
- Improved materials including thin film and ribbon processes
- Higher temperature cells for concentrating collectors including heliostats
- Improved encapsulation, bonding, assembly and installation methods

- Improved slicing processes for silicon cells
- Improved storage, power conditioning equipment, and controls
- Improved test methods and "round robin" testing to enhance ranking and comparisons of the various modules and systems
- Advanced technology including polycrystal devices, electrochemical and multi-band gap cells

## Solar Thermal Power Conversion

- Solar pond technology including stability studies, liner material improvements, thermal cycling and scale-up studies
- Development of improved high temperature materials including metallic alloys, ceramics, and selected coatings
- Improved reliability and performance of tracking systems, receivers, Stirling-cycle engines, organic Rankine engines and Brayton gas turbines
- Improved storage capability and heat exchangers
- Extended operational lifetimes while withstanding repeated thermal shock loads
- Completion of demonstration efforts to obtain R&D feedback
- Assessment of solar thermal for fuels production

## Wind Energy Conversion

- Continued resource assessments and siting analyses
- Need for improved wind loading design data
- Vibration, noise and fatigue analyses
- Improved fabrication techniques and related cost reductions
- Electrical interfacing and integration with utilities
- Improved performance, durability and maintainability
- Continued investigation of advanced concepts

## Ocean Thermal Energy Conversion

- Need for scale-up experience particularly for large heat exchangers and pumps
- Reduction of biofouling and corrosion of heat exchangers

- Advancements in mooring and electrical cable equipment
- Hardware testing to verify component performance and reliability prior to system integration
- Investigation of open-cycle design concepts
- Investigation of advanced systems including mobile systems and submarine design concepts to reduce problems associated with severe weather conditions at the ocean surface

Hydropower

- Resource inventory and site screening
- Need for updating existing equipment to improve performance
- Use of packaged and modular approaches for small-scale systems
- Acquisition of a large variety of environmental and hydrological information for broad-scale utilization

Organic or Biomass Conversion

- Additional resource assessments, screening, and selection of candidate feedstocks (including environmental impact assessments)
- Further R&D needed for processes that liquefy or gasify solid fuels and for multi-fuel combustion systems
- Improvements in large-scale plant growth systems for fuel use
- Improved energy balance and operational efficiency
- Logistics, handling and transportation improvements for a variety of materials
- Systems analysis to match available technology and resources to needs
- Improved test methods and standards to help evaluate comparative performances
- Further investigation of basic photobiology and photochemical conversion processes

Geothermal

- Further assessments of resources, sites and applications

- Development of improved scaling inhibitors
- Advancements in extraction and heat exchange technologies
- Disposal methods for large volumes of salt water
- Removal of non-condensable gases to meet environmental standards
- Recovery of usable gases (methane) as an additional energy resource

Satellite Power Stations

- Need for addressing R&D needs associated with large-scale power conversion, beaming, and tracking using large space structures and transportation systems (certainly a candidate for "long-term, high-risk" technology)

Priorities are urgently needed to establish the relative payoff value of the renewable energy technologies and their respective research and development requirements. A modest amount of funding, carefully placed to further stimulate a proven technology might have a much greater value than the same funds added to a longer term high-risk bet that might never reach maturity. A balanced program is needed to assess each technology from an equitable standpoint and rank the estimated return on federal investments according to the expected energy contributions possible. This is a difficult task but system analysis techniques and methodologies are available, and a comprehensive and coordinated effort should be implemented to accomplish this task. In any event, a balanced and realistic program is needed to efficiently use available government funds.

## COMMON AREAS OF INTEREST

There are a number of common needs that become apparent when reviewing research, development and demonstration requirements for the renewable energy technologies. Obviously the need for more reliable and efficient equipment and lower costs recurs repeatedly, especially since the diffuse and low density nature of solar and wind resources mandates the use of large areas of equipment. And not only the technical problems are in need of attention. Quality demonstrations, large production incentives and improved financial and capitalization methods are likewise in obvious need of support. There are many areas where government assistance would benefit more than one technology and the youthful industry at large. These should be carefully identified and given higher priorities for funding support.

The following listing provides general types of programs which could provide broader benefits and more efficient application of funds.

- Materials research, including aging analysis, accelerated aging tests, glazing and reflector degradation studies, protective coatings, absorber coatings, seals etc.

- Fluids research, including corrosion reduction, water treatments, freeze-proofing, high temperature operation, and physical properties
- Improvement in conversion processings, including thermal, electrical, chemical and optical
- Improvements in all types of energy storage systems and power conditioning equipment (high priority)
- Failure modes analysis, including development of improved systems engineering and design guidelines
- Support of advanced concepts and innovative designs including hybrid systems, cascading, cogeneration and combined technologies (heat-actuated cooling systems using waste heat and solar)
- Improvements in controls and diagnostic instrumentation as well as installation supervision
- Continued deployment of well designed, well placed and carefully monitored demonstration and proof-of-concept systems
- Improvements in heat transfer equipment, including heat pipes, heat exchangers, and insulation materials and methods
- Attempt to realize overall reductions in the costs of solar collectors, conversion devices, and balance of systems without penalizing reliability or performance
- Additional assessments of financial and investment incentives, including tax credits and large-scale government procurements which encourage competition.
- Long term evaluation of operational, maintenance, and reliability data
- Continuing support for resource and siting assessments, environmental design criteria, and improved predictive techniques
- Continuing support for export assistance and overseas demonstrations of quality systems and hardware
- Expanded support of long-term data collection, monitoring, test and analysis of all technologies
- Develop planning, assessment, and methodology tools to compare and select optimum technology and design for various applications

I would particularly like to address the need for additional monitoring and testing to refine and improve the level of performance and reliability already achieved and to validate and verify the relative merits of each renewable technology. Testing activities encompass a broad range of technical expertise and applied skills to properly assess and evaluate renewable energy equipment. They include a number of support program elements as shown in the attached listing:

- Test method development
- "Breadboards" for verification and validation of components/systems
- Instrumentation requirements
- Monitoring systems
- Diagnostics and trouble shooting
- Data processing and storage
- Data analysis
- Environmental testing
- Accelerated aging and lifetime testing
- Performance testing
- Certification and qualification testing
- Acceptance testing
- Lab and field testing
- Safety verification

The skills and supporting equipment requirements are similar for testing of a large variety of components and systems, as the necessary instrumentation and quality control procedures are similar. Testing allows the "proof-of-concept" step to be taken and the continued refinement of the product to be accomplished.

Broadly supported testing efforts as well as consensus test standards are vitally needed by the equipment manufacturers and users to allow comparison, rankings and improvements to evolve. Commercial aircraft are flight tested today under government sponsorship although they have been in development for almost a century. So should large power towers, windmills, and other new systems be operated and tested over long periods of time to allow their full development and assessment. Again, government support and sponsorship is vitally needed to retain the momentum already established and to allow full exploitation of these promising technologies.

A team effort of government and private test laboratories, manufacturers, utilities and other users is essential at this stage to properly assess critical RD&D programs. Without key funding support from federal resources to complete the operational test programs, and to feed the results back into the R&D priorities, a huge public investment may be wasted and needed technologies may be restrained from reaching their early maturity.

# GOVERNMENT ROLE IN RESEARCH, DEVELOPMENT, AND DEMONSTRATION PROGRAMS

The following considerations should be addressed to identify the proper role of the federal government in respect to the funding of new research, development and demonstration programs in renewable energy.

- Perform detailed assessments of the state-of-the-art of each technology including international activities and the extensive R&D efforts underway in private industry.
- Support cooperative and joint efforts such as needed for development of codes and standards.
- Avoid the duplication of R&D efforts and subsidizing competition for activities which are already being successfully demonstrated. Consider the interests and activities of state, institutional and industrial programs.
- Identify what has been completed, is in process and is still needed to satisfy the R&D objectives. Establish priorities and document the results.
- Consider expanded applications and production incentives for near-term technologies through support of uniform testing and evaluation procedures, large-scale government purchases of equipments, continuation of tax incentives and comparative assessments of performance and operation using an equitable basis for evaluation.
- Develop a balanced long-term R&D program which avoids sporadic, stop-and-go funding and is dictated by realistic goals and objectives.
- Strive for quality results, clear-cut answers to RD&D problems and objectives, accurate research and test results, and an accessible data base designed to readily disseminate program results.
- Emphasize R&D efforts which can be applied to more than one technology (such as reflector materials for various types of concentrating solar collectors, or combustion systems which can use a variety of renewable fuels).
- Consider expanded instrumentation and monitoring efforts for on-going federal demonstration sites to obtain feedback and directions for R&D needs. Field testing and evaluation at carefully selected sites could be a very valuable resource which is now being neglected.
- Research and development involves many complex issues besides the technological. Various economic, commercialization, social and other factors must be carefully considered to allow the establishment of priorities and to evaluate overall performance of RD&D programs.

- Improve federal RD&D planning and procurement practices, specifications and technical directions. Also consider decentralization efforts to satisfy regional, state and user needs and interests.

- Strive for balanced programs and schedules which allow the use of basic research, engineering and application efforts to achieve component and system lifetime, reliability, economic and operational goals.

- Consider expanded R&D efforts and advanced concepts which can combine various technologies into total systems (photovoltaics plus wind, salt ponds plus heat actuated cooling, etc.). Hybrid systems will require improvements in federal organizational structures to allow better communication, program management, and integration of technologies.

- Demonstration programs should be considered after a sound R&D base and realistic specifications have been established. Proper demonstrations should emphasize quality and provide a showplace for technology which encourages replication.

- Improve documentation, data base and communication methods to identify R&D results and future needs. Better handbooks, design practice manuals, and guidelines are needed to record project experiences and "lessons learned".

- Improve technology transfer and information dissemination methods to reach a broader audience. A program similar to the NASA "Spinoff" and Tech Briefs effort should be considered to inform researchers, designers, managers, and officials of the current status of energy RD&D programs and highlight selected technology advancements and product improvements.

- Consider new and innovative institutional and financial programs to expand public investment in broadly needed technology programs and involvement in the potential benefits of the investments.

## SUMMARY

Independent test laboratories, such as Wyle, play a vital role in the research, development and commercialization of renewable energy equipment. We have made extensive capital investments in specialized test facilities such as a large solar simulator, environmental test chambers used for photovoltaic modules, and systems test equipment used for solar water heaters. Private organizations are willing to invest their own money to meet the R&D needs of government and industry when long-term commitments of interest and support are evident. Thus, private capital can be applied to relieve the need for government spending in this area.

As service oriented organizations, in close cooperation with government laboratories, private test laboratories provide unbiased evaluations of experimental and other equipment available for operational use. This can provide the manufacturer and the user with the performance and reliability data needed for making product improvements or for equipment selection and use.

At this point in the advancement of renewable energy technologies, clear directions and long-term commitments for sustained programs are needed to support capital investment decisions. The industrial community looks to the government for leadership and selection of priorities for renewable energy research and development, that could provide a more secure energy base in the future. This is particularly true in those areas having high risk and long-term periods before payoff. Both technical and non-technical aspects must be carefully considered and detailed planning efforts performed to select needed programs and activities.

The renewable energy technologies as a group merit a position of strong interest and support. They offer many advantages for allowing energy independence, providing cleanly derived power, enhancing domestic employment and expanding our industrial and municipal bases. Industry is quite willing to invest in developing these valuable resources and will quickly respond to the stimulation of selected areas as indicated by government research and development support on a sustained basis.

Government programs should not discourage private investment and interest in the renewable energy technologies by reducing research, development and demonstration spending. A balanced, long-term, and continuing effort is needed to give new technologies a fair chance to support the transition from using depletable fuels, over to the widespread use of clean, safe, and readily available domestic resources.

In conclusion, the need for alternative domestic energy supplies has not subsided. It is as pronounced, if not more so, today as in the decade of the seventies. The technical capacity to meet that need has also endured admirably. For example, the vast reduction in the cost of photovoltaic hardware, over a relatively brief period, underscores the significant potential for technology advancements and contributions from the government/industrial/university team. During the eighties this potential must be further developed. It will require our concerted efforts and can result in the further evolution of necessary energy resources. Let there be no mistaking the fact: widespread use of energy and power from renewable resources is an attainable reality.

Mr. HEITOWIT. Thank you very much, Mr. Christensen.

We will go to Dr. Cassanova.

Mr. CASSANOVA. Thank you, Mr. Chairman. I appreciate the opportunity to present my views before this committee.

Georgia Tech, as you know, has been involved in solar energy research directly related to the conversion of high temperature solar thermal technology to electricity, processed heat, chemicals and fuels since the early 1970's.

Today I wish to address the need for a modestly funded research program which will broaden the technology base for future solar thermal energy systems and other renewable energy systems through a coordinated effort by universities, private industry and research organizations.

Over the past decade the Federal Government has invested in the development of solar thermal technology through sponsorship of a national effort in private industry, universities, national laboratories, and research organizations.

The Solar I and Shenandoah projects are just two examples of a cost-shared cooperative effort by the U.S. Department of Energy, utilities and State governments which provide developmental experience with solar thermal systems. Other projects are now serving the same purposes for the trough technology. In all of these major developmental programs, universities have played dominant roles for research conceptualization, design and analysis.

The orderly transition of solar thermal technology from predominantly Government financing to private industry and utility financing requires that the Federal Government continue to underwrite the major risks associated with technology development and to provide adequate, continuing funding for a stable technology base upon which solar thermal can expand and improve.

All of the current energy technologies, including coal, nuclear, and petroleum, have required and received continuing Federal support of not only high risk research, but also technology development. Solar thermal technology is versatile in its application, is environmentally benign and should receive adequate funding for technology development and research just as other energy techologies are receiving.

The Solar Thermal Division of the Solar Energy Industries Association has recommended a $59.50-million budget for solar thermal in fiscal year 1983. This budget was described by Mr. Byron Washom during his testimony before the Subcommittee on Energy, Development and Applications on March 16, 1982. Inherent in the STEA budget package is the recommendation that the emphasis of the Federal program be placed, during fiscal year 1983, on the rapid transition of selected, near term, solar thermal technologies into the private sector, while at the same time, attempting to maintain a core solar thermal program concerned with longer term research and development.

The selected technologies that should be supported on a cost share basis by Federal grants until the transition to private hands is complete are the parabolic dish, central receiver and parabolic trough concepts.

While I support the STEA recommendation as a bare minimum budget for transition of these technologies to the private sector, the support for long term research and development is inadequate to build a solid technical base for this renewable energy technology which is so vital to our national energy needs. Long term research and development will not only offer improvements in durability and efficiency for solar thermal technology but will also encourage expansion into future energy markets such as chemicals and fuels. As new concepts and improvements are developed, they should also be transferred in an orderly manner to the private sector for commercialization.

I strongly recommend that budgets related to solar thermal research be substantially increased for fiscal year 1984 and beyond.

Universities, private industry and research organizations have played complementary roles throughout the progression of the solar thermal program. Universities have not only performed relevant and innovative research, but have also played important technical support roles on industry-university design and implementation teams.

The advantages of university participation in technology development and advanced research are multifaceted. University research is highly cost effective through the use of students and faculty who are dedicated to a technology area. A university has highly qualified faculty available in a wide variety of disciplines and can respond efficiently to program needs with minimal shutdown time and costs. By exposing students to problem and goal oriented research, the students gain relevant experience which is a valuable asset when the students join the work force in private industry.

The specialized and dedicated resources combined with an atmosphere conducive to innovation make unviersities uniquely qualified to provide continuity of research.

The national laboratories also have played a crucial role in providing facilities and expertise that industry is unable to maintain. The role of the national laboratories and the Solar Energy Institute should continue to be supportive of the solar thermal technology needs which cannot be addressed by private industry or universities.

The emphasis at the national laboratories should be on stimulating participation and providing complementary contributions to the technology rather than competitng with universities for research funds or absorbing research capabilities already in place at universities or private industry. The dispersion of expertise throughout the scientific community, rather than concentration in a small number of laboratories, will result in higher productivity and more innovation. It is in the best interests of the solar thermal program, both technically and financially, that university, industry and research organization resources and capabilities be encouraged and enhanced by continuity of funding available to these categories.

The solar thermal research facilities are valuable national resources which are essential to maintaining a technology base for current and future solar thermal reserach and development. These facilities are essential for verification of components and systems, and for exploratory research under real solar conditions. Federal support for these facilities is needed to maintain a minimum state of readiness for use by private industry and universities.

These essential facilities include the central receiver test facility, the test bed concentrators and the advanced components test facility.

The advanced components test facility [ACTF] at Georgia Tech has proven to be an extremely versatile and cost effective facility for high temperature materials research, advanced component development, high temperature-receiver designs and chemicals/fuels reactors. A number of experimental programs have been successfully conducted at the ACTF since operation began in 1977 and are documented in DOE reports.

The universities in the United States represent an important technical resource for performing task-oriented solar thermal energy research. The expertise in the academic research community is large and diverse and should be applied in a coordinated manner towards innovative solutions to anticipated development requirements. The research center concept provides a mechanism for a concerted technical thrust by a qualified research team which is funded for a time sufficient to provide continuity in the research program direction and in senior personnel involvement.

The Georgia Institute of Technology and the University of Houston have proposed to DOE and have received partial funding for a coordinated solar termal advanced research center program. These centers should be funded at a minimum combined level of at least $1 million in fiscal year 1983 with substantial increases for fiscal year 1984 and beyond to accommodate growth and other additional qualified universities.

The full potential of solar thermal technology can only be achieved by an advanced research program which parallels and is coordinated with the technology development efforts of private industry and the Federal Government. A viable advanced research program should include the following elements: Long range, multiyear financial commitment by the Federal Government; an open forum for scientific review of research direction and progress; and mechanisms for funding of innovative ideas and critical research in universities, private industry, and research organizations which have the necessary resources and interests.

There is a natural tendency to make programmatic decisions based on the market potential and economics of a product. While this decision process may be valid for near term planning, it is an inapproriate technique to use in determining the viability of a commodity in the marketplace a decade or two later as both the needs and the economics of the market are subject to drastic changes.

Furthermore, a number of research needs can be identified which are required irrespective of the final product. These research needs are generally directed towards processes yielding higher solar to in-product conversion efficiencies. Such processes generally require the study of chemical reactions or require high thermal flux research, taking advantage of the unique properties of solar thermal energy. Supportive systems studies which integrate components to produce viable overall system performance of the requisite high fluxes are also needed.

Thermionic energy conversion is a technique for direct conversion of heat into electrical energy. Thermionic devices are now available which utilize heat at 2700° Fahrenheit to general electric current. Thermionics are a very attractive match for topping cycles in solar power plants, fuel production reactors and high temperature electrolytic hydrogen production. Research on thermionic receiver design and solar thermal process matching should be pursued to determine the full potential of this unique technology.

Additional technologies which are currently in the development stage should also be analyzed for solar thermal compatibility. Examples are the sodium heat engine (a solid electrolyte, thermally driven device under development by Ford) and photo electro-chemistry (solar illumination of semiconductor surfaces in a wet chemical cell). Both of these processes can also be adapted to the production of hydrogen.

Hydrogen could be an important fuel, energy storage medium and chemical feedstock in the future. High temperature water vapor electrolysis has high potential for very attractive conversion efficiences and low cost and is a particularly promising match with high temperature solar thermal capabilities and thermionic topping cycles. At present, the most active research on high temperature electrolysis is being conducted in the Federal Republic of Germany. A program for U.S. research in this promising technology and investigation of solar unique applications should be supported by the Federal Government.

In summarizing my comments, solar thermal technology is in a transitional phase of technology development which requires continued government support for the established Government-industry partnership. The technology has achieved a stage of maturity where the needs for long range research to expand the potentials of solar thermal can now be addressed. The universities in cooperation with private industry have played a vital role in the progression towards development of this vital energy resource and remain a cornerstone for the future expansion of the solar thermal technology base.

I look forward to the possiblity of working with the House Science and Technology Committee as budgetary recommendations are put forth on the research needs of solar thermal technology.

I appreciate the opportunity to provide a research perspective to this committee.

[The prepared statement of Robert Cassanova follows:]

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Universities, private industry and research organizations have played complementary roles throughout the progression of the solar thermal program. Universities have not only performed relevant and innovative research but have also played important technical support roles on industry-university design and implementation teams.

The advantages of university participation in technology development and advanced research are multi-faceted. University research is highly cost effective through the use of students and faculty who are dedicated to a technology area. A university has highly qualified faculty available in a wide variety of disciplines and can respond efficiently to program needs with minimal starting and shutdown time and cost. By exposing students to problem and goal oriented research, the students gain relevant experience which is a valuable asset when these students join the work force in private industry. The specialized and dedicated resources combined with an atmosphere conducive to innovation make universities uniquely qualified to provide continuity of research.

The national laboratories also have played a crucial role in providing facilities and expertise that industry is unable to maintain. The role of the national laboratories and the Solar Energy Research Institute should continue to be supportive of the solar thermal technology needs which cannot be addressed by private industry or universities.

The emphasis should be on stimulating participation and providing complementary contributions to the technology rather than competing with universities for research funds or absorbing research capabilities already in place at universities or private industry. The dispersion of expertise throughout the scientific community, rather than concentration in a small number of laboratories, will result in higher productivity and more innovation. It is in the best interests of the solar thermal program, both technically and financially, that university, industry and research organization resources and capabilities be encouraged and enhanced by continuity of funding available to these categories.

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The full potential of solar thermal technology can only be achieved by an advanced research program which parallels and is coordinated with the technology development efforts of private industry and the federal government. A viable advanced research program should include the following elements:

Long range, multi-year financial commitment by the federal government.

An open forum for scientific review of research direction and progress.

Mechanisms for funding of innovative ideas and critical research in universities, private industry and research organizations which have the necessary resources and interests.

There is a natural tendency to make programmatic decisions based on the market potential and economics of a product. While this decision process may be valid for near term planning, it is an inappropriate technique to use in determining the viability of a commodity in the market place a decade or two later as both the needs and the economics of the market are subject to drastic changes. Longer term research programs can prepare us for some of these changes. Furthermore, a number of research needs can be identified which are required irrespective of the final product. These research needs are generally directed towards processes yielding higher solar to end-product conversion efficiencies. Such processes generally require the study of chemical reactions or require high thermal flux research, taking advantage of the unique properties of solar thermal energy. Supportive systems studies which integrate components to produce viable overall system performance of the requisite high fluxes are also needed.

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## SUMMARY

Solar thermal technology is in a transitional phase of technology development which requires continued government support for the established government-industry partnership. The technology has achieved a stage of maturity where the needs for long range research to expand the potentials of solar thermal can now be addressed. The universities in cooperation with private industry have played a vital role in the progression toward development of this vital energy resource and remain a cornerstone for the future expansion of the solar thermal technology base.

I look forward to the possibility of working with the House Science and Technology Committee as budgetary recommendations are put forth on the research needs of solar thermal technology. I appreciate the opportunity to provide a research perspective to this committee.

Mr. HEITOWIT. Thank you very much, Dr. Cassanova.

We will now hear from Dr. Charles Groat.

Mr. GROAT. Thank you, Mr. Heitowit. I am going to speak to a little more of a specific topic. My particular interest is in the geothermal area, more specifically, the geopressured-geothermal resources in the Gulf Coast area of the United States.

My interest stems from my role as State geologist. The Louisiana Geological Survey is a nonregulatory organization and among other things we are charged with assessing the energy and mineral resources available to the State. Prior to assuming my position in 1978, I was involved in a similar program in Texas at the University of Texas, so I have been in geothermal research essentially since the program got underway.

As I am sure you are aware, geopressured-geothermal energy is the new girl in town. It stems from the Arab oil embargo and it was really that period when the large resource numbers put forth by the U.S. Geological Survey caught everyone's attention because it looked at that time as if it would solve not only the goal of solving industry's energy problems, but everybody else's. At that time the Federal Government got involved and really has carried this program through a logical sequence of investgations since that time.

Not all have been fruitful, but the sequence has been logical and one of the first questions to be answered was the resource assessment question. How much is there that can be recovered, not simply how much is actually there. And so the early funding at the University of Texas and Louisiana State University was aimed in that direction. At that time we were seeking a resource that could be used, through its hydraulic and thermal components and the methane that it contained, for large scale electricity generation. One of the early things we learned was that that it probably would not work. We could not find reservoirs big enough to produce the tremendous volume of fluids necessary to do that job. Then something happened that gave new life to the geopressured resource and that is that natural gas prices continued to rise. This resulted in a shift in emphasis from thermal electricity generation by an exotic energy resource to extracting from it a very conventional and easy to use resource, natural gas. This became the thread that we began to follow in more detail.

The next step in the assessement is testing the resource and this is really the crux of the geopressured, geothermal research program. It is the part of the program that we are on the brink of, and where we feel most frustrated because it doesn't look like we are going to finish what we started.

The geologists and engineers have been able to narrow down the scope of the resources from hundreds of trillions of cubic feet to more realisitc numbers that range from 50 to a couple of hundred trillion cubic feet. It is still a significant resource, but in terms of its productability, in terms of the mechanism of production, it is an extremely high risk resource. The petroleum industry and the energy industry in general is not going to get into the business of producing geopressured methane until it becomes a competitive target with conventional resources and that is not going to happen until two things have occurred:

First, they run out of good targets for conventional resources and secondly, the high risk questions which the federally funded program has sought to answer are answered. Hopefully the answers will lead to resource development, but we haven't answered them yet. The question of when we can produce large quantities of hot fluids from commercial-sized reservoirs and produce gas that will be commercially competitive has not been answered. The answer depends on the text well program consisting of short-term tests of conventional wells and very expensive long-term tests of wells designed to produce large volumes of fluids. Four of these designed test wells have been drilled, three in Louisiana and one in Texas into four representative geopressured, geothermal reservoirs of commercial size. Each well cost $10 to $12 million.

DOE has made the major investment that had to be made to answer the questions of productability: Can those fluids be produced at high volumes for long periods of time?

The frustrating part of the program is that we are on the brink of conducting those tests and we don't have enough money to do it. The administration's budget of $2.44 million for 1983 simply will not allow that testing to proceed and the testing must proceed for at least 2 years if we are to find out whether this energy source is a viable one.

The three questions that we really have to answer in the 2-year testing process can be summarized as: (1) whether our predictions of the extent of the resources in these resources are accurate or not, (2) whether we can produce the resource at commercial rates without undue maintenance cost and perhaps more important or at least as important (3) are some of the environmental issues that surround the resource going to be difficult to deal with?

Subsidence is a possibility. We can't tolerate additional subsidence in our coastal areas so a fairly expensive and aggressive monitoring program has to accompany the testing to measure subreduce. If the resource is productable, if we don't have subsidence, and when gas prices are high enough to encourage the private sector to get into the business, then we will have a resource available for use.

As it was in the beginning of the program and as it is even more so now, it is the proper role of the Federal Government to take those resources whose day of utilization is many years in the future, bring them to a state of understanding so that when the short-term economics allow it, the private sector can get involved. We are on the brink of achieving that understanding and to do that we must complete the testing of the four wells.

So my recommendations to the committee are fairly simple, fairly straightforward. It is dollars. To accomplish what we must in 1983 we need a funding level of approximately $17 million. To test all four design wells, to continue the environmental monitoring and to continue much of the important research that has been going on at several universities, most notably Louisiana State University and the University of Texas, in reservoir modeling, materials research; funding at this level is necessary.

We must also reevaluate the thermal component. It kind of got lost in the shuffle as we concentrated on methane, but the fact is that we have greater than 300 degree farenheit thermal resources which can have applications. This energy source should not be forgotten and it should be brought back into the forefront in 1983 and beyond.

We need in 1983 $17 million to complete the testing to continue the environmental monitoring and wrap up the university research that has been contributing to the program.

And in 1985, we actually do see a conclusion. This is not an endless Federal program. By 1985 the major goals of the program that the Federal Government started in the early 1970's will have been reached. We will have conducted tests, we will have answered the key questions. We need to continue the environmental monitoring for that year because there are potential lag effects that must be monitored beyond the testing.

So by 1985, hopefully we can close out the program we will have answered the questions and funding levels that are relatively small for the development of a resource that could play an important role when the economics allow it.

That concludes my testimony.

[The prepared statement of Mr. Groat follows:]

## PREPARED STATEMENT OF CHARLES G. GROAT, STATE GEOLOGIST AND DIRECTOR, LOUISIANA GEOLOGICAL SURVEY, DEPARTMENT OF NATURAL RESOURCES

I am Charles G. Groat, State Geologist and Director of the Louisiana Geological Survey, a component of the Office of the Secretary, Louisiana Department of Natural Resources. The Louisiana Geological Survey is a nonregulatory organization charged, among other duties, with assessing the state's energy and mineral resources. In this capacity we, in cooperation with Louisiana State University, have been heavily involved in evaluating the geopressured-geothermal resources in southern Louisiana. Prior to assuming my present position in 1978 I was involved in a similar program in Texas conducted by the University of Texas. My comments today stem from my experience in both programs.

### Introduction

Geopressured-geothermal energy can be deemed the "new" geothermal resource. It wasn't until the period of intensified interest in alternative energy resources that followed the 1973 Arab Oil Embargo that this form of geothermal energy received widespread attention. Resource estimates based on work by the U. S. Geological Survey suggested the presence of a tremendous resource base, composed of hydraulic, thermal and dissolved methane compounds, one that could provide a major contribution to meeting regional and national energy needs. These estimates and the interest in the geopressured resource they stimulated, resulted in the development of the geopressured-geothermal energy program in what is now the Department of Energy.

In the early 70's, federal geothermal research funding was concentrated on the more traditional hydrothermal and hot-dry rock resource types. Competition for funding was keen; but the geopressured-geothermal program grew throughout the 70's, following a logical progression of investigation types. This progression is on the brink of being halted at a time when a relatively few million federal dollars can bring it to its logical conclusion and validate the federal funding that has been previously committed to geopressured-geothermal programs.

Early federally-funded geopressured-geothermal research programs stressed resource assessment. It was important to understand the magnitude of the resources in terms of recoverable energy under various economic conditions. This resource assessment program also sought to delineate sites that represented the types of reservoirs that could yield energy in commercial quantities and where designed test wells could be drilled and tested. A Wells-of-Opportunity program that would allow shorter-term testing of a larger number of reservoirs was implemented in the middle 70's. During this period numerous studies dealing with reservoir modeling, test well design, materials, energy conversion equipment, socioeconomics and environmental impacts, resource economics, legal constraints and other aspects were funded by the federal government.

During the late 1970's the emphasis in geopressured-geothermal programs took a significant turn. While both the thermal and dissolved methane components of the resource had received attention throughout the program, early emphasis had been on the thermal component and its use in electricity generation on a large scale. During the same period that studies were indicating an increasing number of problems with this approach, natural gas prices were rising. This prompted the focus that continues to the present time: the concentration of interest on the dissolved methane.

This shift from emphasis on an unconventional form of geothermal energy frought with problems in making conventional use of the thermal component, to an unconventional source of a very well known and easy to utilize resource, methane, gave new significance to the geopressured resource. It did not reduce the significance of the technological and economic problems to be solved, but it did put the future of the resource more in terms of "at what prevailing price for ~~material~~ natural gas is geopressured methane viable" rather than "how can we utilize the heat under any reasonable set of industrial or power generation engineering constraints?" The problems to be solved thus become concentrated in the area of reservoir properties and production engineering rather than utilization.

## Importance of the Federal Government's Role

Competing as it does with conventional sources of natural gas, geopressured methane is a high-risk resource; commercialization will not occur until the energy production sector, chiefly the petroleum industry, perceives that the opportunities afforded by exploration for and production of geopressured methane is as attractive a risk as is the finding and development of conventional reservoirs. This has not occurred up to this point and will not occur until the major questions the federally-funded program set out to answer have been dealt with, hopefully in a positive way. These are:

1. The extent of the resource; the distribution of reservoirs that can produce fluids with suitably high methane contents in commercial quantities;
2. The engineering feasibility of producing the resource at commercial rates, for an adequate length of time to insure pay out and acceptable profits; and
3. The environmental consequences of fluid production and disposal. Major subsidence in the coastal areas where geopressured resources occur is possible, but is unacceptable. Impacts of geopressured resource production on subsidence rates must be determined through monitoring.

If these questions are answered in an acceptable way, the geopressured resource will be developed at the time that gas prices permit it and when conventional gas reservoirs do not offer significantly more attractive targets, largely because discovery rates have become discouraging.

Industry has not traditionally funded resources research of this type; it is the proper role of the federal government to insure that resources whose day is far in the future are considered, researched and readied for development when economic conditions allow the private sector to deal with them. We cannot afford the luxury of allowing the short-term economic considerations of industry to determine the fate of this nation's energy future in the area of resources which are high risk under present engineering and economic conditions. The Department of Energy and U. S. Geological Survey have brought geopressured-geothermal energy resource knowledge to the brink of an acceptable level. Industry has provided some support and the Gas Research Institute has taken a major interest and funded important parts of the program. It remains, however, the responsibility of the federal government to complete what it started.

Program and Funding Needs

Finding answers to the major questions surrounding geopressured-geothermal resource viability depends on long-term testing of the four designed test wells already drilled: three in Louisiana and one in Texas. Completed at a cost of more than $40 million, these wells can produce the data needed to provide a reasonable level of understanding of the critical production parameters. The $2.44 million requested for the DOE geopressured program for 1983 will not allow for this testing and with no funding planned for 1984, a year during which testing should continue, the chief objectives of the multiyear DOE program will not be met. This is not only a short-sighted approach to funding, it is wasteful, To bring the geopressured-geothermal research program to a meaningful conclusion, the following program and funding elements are essential:

FY 1983. Funding level: $17 million. Activities in FY 1983 should include:

1. Testing of all four designed test wells (Gladys McCall; Dow Sweezy #1 and Sweet Lake in Louisiana; Pleasant Bayou #1 in Texas);
2. Continuation of environmental monitoring (subsidence, seismicity, water quality) at all four designed test well sites;
3. Continuation of reservoir distribution and properties research at universities in Louisiana and Texas and through contracts with consulting firms for modeling and reservoir performance evaluation. Reevaluation of commercial applications for the thermal component.

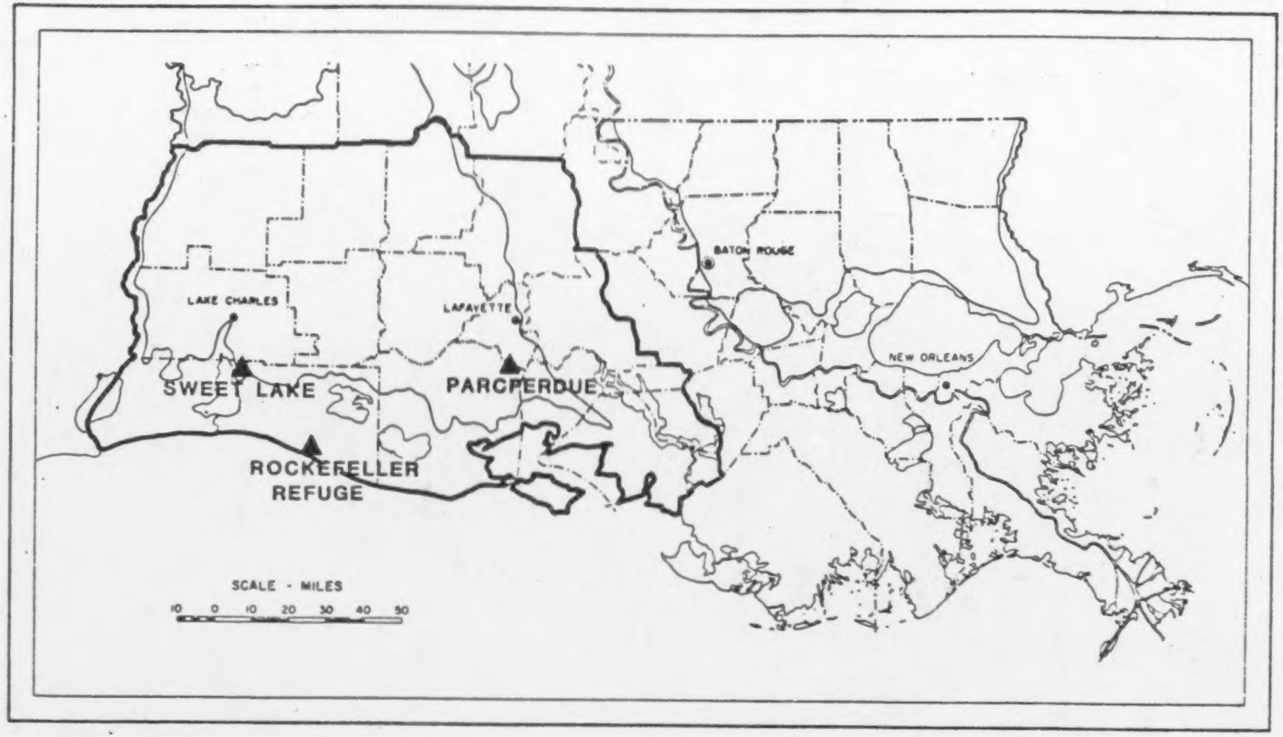
FY 1984. Funding level: $14 million. Activities:

1. Completion of long-term testing at all four sites;
2. Continuation of environmental monitoring;
3. Wrap up of geological and reservoir analysis at universities and by other contractors; and
4. Preparation of final resource assessment and producability reports.

FY 1985. Funding level; $5 million.

1. Continuation and completion of environmental monitoring to determine lag effects of production on subsidence rates;
2. Close-out of testing program. Continuation of topical research at universities, laboratories and by consulting firms.

LOUISIANA DESIGNED TEST WELLS



Parcperdue is Dow Sweezy #1
Rockefeller Refuge is Gladys McCall

Summary

The successful completion of the geopressured-geothermal resource research program depends, as did the inception of the program, on funding by the federal government. Continuation is fully justified under the long-term, high-risk criteria posed by the administration. Regardless of whether the recoverable resource is actually 50 or 5,000 trillion cubic feet, the quantity is significant. Federal funding is essential to bring previous federally funded programs to a logical conclusion and provide the information that the private sector can build on when economic and conventional resource opportunities dictate that it can take an active role in producing geopressured-geothermal energy. To accomplish these objectives federal funding is needed at the following levels:

| | |
|---|---|
| FY 1983 | $17 million |
| FY 1984 | $14 million |
| FY 1985 | $ 5 million |

Mr. HEITOWIT. Thank you, Dr. Groat.

We will go to a short question and answer period now and I will start with my colleague, Gene Frankel.

Mr. FRANKEL. Mr. Christensen, you have a lot of experience with testing solar equipment. This seems like a proper Government role. Could you give us guidelines as to what is the best way to set up a Government testing program for any new solar technology? What mistakes should be avoided? What has been done well in the past?

Mr. CHRISTENSEN. I think there are some common elements and lessons we have learned, but I would point out the great diversity of each of these solar technologies and to some extent they have different test requirements.

On the other hand, there are many common elements in testing that I think the Government should address and I think by support some of the common needs as I mentioned, you could benefit the largest number of potential users. But certainly, test standards are needed and I might mention in biomass, for example, we recently had to write the test standards for some equipment that converted biomass to oil base, as the test standards did not exist.

I think someone should be looking at the whole arena of test standards for renewable energy and see what exists, what doesn't exist and continue to support that kind of acitvity. In some cases like solar collectors, there have been many years of effort going into test standards, but I think, as Dr. Block has pointed out and well knows, there is still room for improvement. We still don't have all the answers.

So, in some cases there are no test standards and in others there are test standards, but they are not adequate. I would like to emphasize the role of government to help support the logical development of test standard procedures and certification procedures for equipment, not to regulate, but to cooperate and provide some financial support to the institutions and organizations trying to develop them.

Mr. **Steinway**. Could I follow up on these questions if you don't mind?

Mr. **Heitowit**. Please do.

Mr. **Steinway**. Thank you very much. To follow up on Dr. Frankel's questions, one of the issues that the committee has been extremely interested in is the question of standards and who should be developing them. Should they be Federal standards or industry consensus voluntary types of standards?

Specifically, for example, in the small wind program, should we have a mandate of Federal standards that protect safety interests of consumers or could industry pick up the slack and develop these standards on their own?

We have asked for information on this point from the solar industries associations, for example. What are your feelings on the pros and cons of Federal standards versus industry standards? What do you think is the best approach to help accelerate the development of these new technologies?

Mr. **Christensen**. You want me to attempt that?

Mr. **Steinway**. Yes.

Mr. **Christensen**. I think the use of consensus standards is certainly the preference of industry as opposed to dictatorial standards by the Federal Government. But I do think a cooperative effort (much as we have seen in the codes and standards effort and the SRCC efforts in solar hot water systems) is needed. When I say cooperative, I do mean some bucks need to be spent to accelerate the effort and help it along because frankly, a lot of individual companies that have members on the standards committee's cannot afford all the numbers of meetings that are required. I think you will get this same feeling from ASHRAE and from many of the established technological institutions. They do want Government support, not dictation, and they need some financial help in order to accelerate the process.

But to answer the question, I think it should be a consensus standard with certain government support and overseeing if the question of public safety gets into the picture. They you may need a little more government and/or utility involvement.

For example, with windmills, I guess the evolution has been slower than with hot water systems, because there were a lot more hot water systems out there and it has moved a lot quicker.

In the case of small wind machines, I know there is Government sponsored testing going on at Rocky Flats in Colorado.

In the case of the intermediate sized machines there are some problems right now, that are not necessarily being properly addressed.

In summary, this is a very diverse and complex subject and each one of these things needs to be addressed individually and in much more detail.

Mr. **Frankel**. Thank you.

Dr. Cassanova, you talked about the role of universities and research labs. It is an issue that we have wrestled with a lot on the committee, the relative roles of industry, the universities and national laboratories. I wonder if you have any guidelines for federally funded programs as to what role industry should play, what role the national laboratories should play and so forth?

Mr. Cassanova. I think ideally you would like to have a joint university industry teams to do research programs. The national labs, I think, fill a very important role. If they have capablilities that are not in place at universities or in private industry, I think there is a crucial need for the national laboratories, but I also think there is a tendency to collapse a lot of the cababilities into these national laboratories rather than trying to enhance the linkages between unversities and private industry.

The universities can provide very cost effective research that is not in place in private industry and with private industry can form a very cost effective and productive team to not only do research, but to produce some final product for the marketplace.

So, I think you can't consider universities by themselves. You don't want to isolate universities and say here is a pot of money, go off and do your long range reserach and forget about the needs of society and forget about the needs of private industry. I think it has to be a jointly coordinated program with private industry.

Mr. Frankel. Is there anything the Government could do to promote that coordination between industry and the universities?

Mr. Cassanova. I think there are many areas of research that can be done jointly, very effectively by private industry and universities, but private industry is not willing to provide the funding for that.

I believe that the Federal Government should provide the funding for this long-term research that can be conducted by universities and private industries.

Mr. Steinway. Mr. Christensen, your testimony is somewhat different from the testimony we received this morning where a number of the witnesses said we should abandon the shotgun approach to the solar development and focus on three or four main technologies. In your longer statement, you recommended that we keep going in all eight areas. I am wondering if that is based on an assessment on your part that all eight deserve further support or have you done some assessments to indicate that the other witnesses are wrong, that we shouldn't abandon any of the technologies?

Mr. Christensen. To clarify that, I did list in some detail a number of research and development needs in each of the technologies and then I followed up with a statement that we should apply research and development priorities and value criteria on these similar to what we heard today. We need to look at all of them and not make prejudgments at this point until we go in and apply the methodology and see what the potential is for each technology. Each individual has a certain bias toward a certain technology and I can understand that, but I think we should try to be a little more unbiased. Before we make hardnosed decisions, we should look at each one of these and their relative merits.

In some cases we might have ruled out a technology although someone may be working on a breakthrough. I could cite some examples for that. The technology may be penalized because up until now it hasn't reached any form of maturity, but a small breakthrough or different approach could make that technology worthwhile. We shouldn't neglect it because no one has achieved it yet.

So I think we need a balanced viewpoint and a systems analysis approach to look at each of these technolgies without just making decisions off the top of our heads.

Mr. **Steinway**. In early days, DOE did a lot of sytems analysis. Are there any striking successes. On the contrary are there any striking examples of poor assessments that led to mistakes?

Mr. **Christensen**. I would like to point out there is an urgent need for solar cooling because of its load matching capability, obviously on a hot, sunny summer day you need more cooling. I think we should reassess some of the opinions that have developed concerning active solar cooling as there may be some techniques that now look very promising.

What I am saying is we don't really know until we go through the full R&D effort and really try to develop the technology.

Mr. **Steinway**. Thank you.

Dr. Groat, I would like to ask you a question referring to the activities of the geopressured program in methane. Do you think it might be more useful from a management perspective to look at the program in the context of the fossil program now rather than the geothermal program since you are now emphasizing obtaining methane from the geopressured resource?

Mr. **Groat**. Well, it is my understanding that this has been under discussion within DOE for some time as to where it really belongs and I think it is very true that the technology involved in recovering not only the methane, but the geothermal resources is more akin to the fossil fuel technology, specifically that of the petroleum industry. I think it should be placed wherever it could be managed in the most complementary enviroment. More traditional geothermal programs within the division of geothermal energy through reprograming could take funds from the geopressed-geothermal program which would shorten the program even more. If it was the opinion of Congress that this was important enough to continue and it appears that it would do better in the fossil energy program and should be put there because it needs a home where it is with its family and that may be fossil more than goethermal.

I really think that the long term impact of the resources is going to be in the area of the gas rather than the thermal energy. In the local geothermal applications the heat may be significant, but it would be a byproduct.

Mr. **Steinway**. Very briefly, what impact do you think deregulation will play in the stimulation of geothermal resources?

Mr. **Groat**. I think it will bring development closer. I think the effect of deregulation will be to speed the exhausting of conventional targets. This is going to bring more interest in more marginal conventional targets and unconventional ones; it will cause them to be explored more rapidly because there will be more capital available and it will come to a time when geopressured methane will be among those targets. This will speed its development.

Present incentives which allow pricing of geopressured gas at an unregulated rate and the tax incentives hadn't worked at this point and I don't think they will until conventional targets are less appealing. That will come with deregulation.

Mr. HEITOWIT. If you would yield, do you currently have private sector involvement or active interest from the producers in your program?

Mr. GROAT. We have had spotty interest from the major petroleum companies; they have cooperated and provided technology, but not major funding, although they have funded some programs at the University of Texas. The Gas Research Institute has made significant contributions of dollars. They have been the strongest industrial supporter of this program.

Mr. HEITOWIT. Very fine.

Thank you.

Well, we finished our morning program basically on time. We want to thank you gentlemen for your contribution. Your statements have been very helpful to the committee. We will stand in adjournment until 2 p.m., when we will resume with the afternoon panel on the subject of biomass.

## AFTERNOON SESSION

Mr. HEITOWIT. Good afternoon. We would like to reconvene the subcommittee symposium on renewable energy. The special topic this afternoon is biomass.

The first witness is Mr. William Bulpitt, Technology Applications Laboratory, Georgia Institute of Technology in Atlanta.

We have your full statement and your appended materials which will be placed in the record, and we would like you to abbreviate your statements as much as possible, summarize if you could, to give us a little more time for questions.

Mr. Bulpitt, proceed, please.

## STATEMENT OF WILLIAM BULPITT, TECHNOLOGY APPLICATIONS LABORATORY, GEORGIA INSTITUTE OF TECHNOLOGY, ATLANTA, GA.

Mr. BULPITT. Thank you.

We at Georgia Tech are pleased to have the opportunity to address the Subcommittee on Energy Development and Applications this afternoon. The Engineering Experiment Station at Georgia Tech is the main research arm of Georgia Tech and has about 700 full-time employees, many of whom are engaged in various aspects of energy research.

We have carried out many activities in the past that have benefited Georgia industry in general, and we first became active in a number of energy-related programs in 1977, through the State office of energy resources.

We established what is known as the Industrial Energy Extension Service, which helps a number of the industries in the State solve their energy use problems.

About 5 years ago, we got involved in some wood energy activities along with the Georgia Forestry Commission, which is also represented here today. We had a seminar in Atlanta on industrial wood energy use and some 250 people attended, and from this we determined that there was a great deal of interest in this subject.

This initial interest from this seminar grew into other activities in a number of other programs relating to biomass research.

Most of these—in the interest of time—most of these are summarized in the paper that you have been given, so I won't go into details on these, but suffice it to say that we have been very well supported by the Department of Energy in many of these activities, and I think that the spirit with which the program was started was essentially carried out to the fullest extent. One of the biggest programs we had with DOE was one we called the State wood energy demonstration program. Basically there were four major tasks to be accomplished in this program. One was the conduct of certain site-specific feasibility studies for industrial plants for wood energy conversions in the State of Georgia, and over 2½ years we did some 35 of these. About 75 percent of these studies did indicate that it was a feasible proposition to use wood as a fuel for steam production for textile mills, food processing plants, and other Georgia industries.

Unfortunately, I can't relate to you that all these feasible sites are currently under construction, because of the current problems with getting loans for capital improvements. We feel that over the next 5 years, however, that there is going to be a big movement in the State of Georgia toward solid fuel for industry and we have sort of planted the seed with a number of industrial plants in looking at these alternate energy forms.

Now, to go one step further, two of our projects have involved the actual construction and startup of large wood energy facilities for industrial plants, and I have some of the literature and material on the table which addresses those plants in more detail.

We have also looked at some of the specific processing questions that needed to be addressed, such as storage of biomass fuels, the optimum ways to process the fuels, the most beneficial methods to be used for processing wood fuel into better fuel, and also questions in handling and storage.

Lastly, we have had a very large activity in the technology transfer area, which resulted in the distribution of more than 45,000 items of literature describing our projects and describing activities in the biomass field in general.

Now, the point I am trying to make here is that under DOE sponsorship, we were able to accomplish a number of things that have been beneficial not only to the State of Georgia, but programs that have also been imitated by the other States in the Southeast.

We have been asked to be speakers at a number of different symposiums on various subjects related to wood energy. We have worked very closely with the State of North Carolina in a number of their wood activities, and we also assisted people in Florida and Alabama in their activities.

Through the course of these studies and these projects that have gone on for the last 2½ years, we have come to a number of conclusions as to what is needed further in the areas of research, in particular the areas of Government-sponsored research.

I would like to go into these in a little more detail.

Toward the end of the testimony here, basically we have discovered we have done a lot of work in the areas of thermal gasification of wood. We have a pilot plant operation on the Georgia Tech campus of the 2 million Btu per hour range.

We have assisted Mr. Shirley and other members of the Forestry Commission in their large low-Btu gasification project in Georgia, and we have done a number of feasibility studies in looking at the use of wood gas as a fuel for other industries in the State, particularly the textile industry.

We carried out a number of experiments on direct drying of textiles using wood gas, which were very favorable. We are looking for further activity in this area. Natural gas for textile drying is one of the largest uses of the textile industry, which is so important to our State.

We have also looked at the mineral industry with American Cyanamid as one plant, typical of a number of other processing plants. There we have looked at the use of wood gas as a fuel for their large drying and rotary kiln operation.

With our activities, what we find basically in this area is that further development and new processes to produce medium Btu gas from various biomass feedstocks are definitely needed. There are a number of these activities currently being funded by the Department of Energy, and we see that this is a need that will continue, and if many of these activities are no longer supported, there will be a serious gap in the thermal conversion area resulting from these cancellations.

Another area where we see further research needs is in the area of gas cleanup for both low and medium Btu gas production processes. There has been a particular question with regard to running engines with this gas and, as was mentioned at our luncheon today, the Philippines have a truck here that is using charcoal gas as a motor fuel. The problem with many of the applications for engines is that the level of cleanup needed is very much higher than a normal boiler application, and, for the long term, the cleanup question is one that has not been fully dealt with.

There are certain aspects of pollution control with regard to wood burning which are still not fully understood. In particular, nitrous oxide emissions is an area where EPA needs more data, and also with regard to the combustion of agriculture residue, this is an area where data is lacking.

Other environmental effects need further consideration. Long-term storage effects of biomass fuels, what are the effects of tile runoff, and what are the local environmental problems that result from the use and storage of these fuels.

Certain aspects of machinery development still need to be done, and, again, these will not always be done by the private sector alone, without some Government support. We talked today at lunch about the pelletizing area and other areas in the fuel beneficiation field that need further research.

One other area that we have read a good deal about, and we have not heard too much about in the State of Georgia, because we have so much wood residue and low-grade wood currently available, are the short rotation concepts for fuel plantations, where there are a lot of question marks in this subject area right now, particularly with regard to fast-growing tropical species that can be of use in Third World countries and other countries that we are trying to assist in a number of our research activities.

Again, agricultural residues are an area that need to have further support in research. I am working as a consultant right now with a company in California that is looking to take agricultural residues and generate power. There are still a number of questions about the properties of these fuels and how they would be accepted environmentally, and what the overall effect is on the State's agricultural economy.

Institutional issues come up in the areas of cogeneration with wood fuels and biomass fuels, and there is certainly a further role of Government in these areas.

I want to stress, also, the continued need for technology transfer of research activities, particularly when the Government is concerned. We feel that on many of the things that we have done in the State of Georgia regarding wood fuels, we have gotten the word out to potential users. We have, along with Ray Shirley and the forestry commission, had a number of successful seminars, programs, production of filmstrips, and publications that have really gotten the word out in front of the people in our State, and I feel that when capital budgets of companies do loosen up, there will be further installation of wood-fired facilities. But, let it not be underestimated the role that Government has to play in this kind of activity.

The plants that we have been working with, for instance, the ones that we have installed actual facilities in, the integrated product textile mill and, soybean processing plant, that are mentioned in the literature and also the American Cyanamid plant that is now going to be installing a large wood gasification plant, none of these companies would have gotten into this field and looked at it seriously if it were not for the activities of Georgia Tech in the biomass field and our ability to assist them.

So many production-oriented companies are not in the business of energy; they don't understand a number of these new processes that are becoming available; and to say that the free market will completely take care of all new energy sources, I think, is somewhat naive. There is going to be a continued need for technical assistance and transfer of technology in the biomass fields to industry in our State and in the country as a whole.

In regard to the Third World nations, this is another important area. We are getting ready to respond to an RFP—request for proposal—from the Philippines in the area of wood energy, and we feel that there are a number of things, a number of research activities going on in the United States right now that could be used to benefit people that we are trying to assist around the world in the areas of energy.

I think I have taken all my time. I appreciate the chance to be here, and I would be glad to answer any questions.

[The prepared statement of Mr. Bulpitt follows:]

## PREPARED STATEMENT OF WILLIAM S. BULPITT, SENIOR RESEARCH ENGINEER, GEORGIA INSTITUTE OF TECHNOLOGY ENGINEERING EXPERIMENT STATION

We at Georgia Tech are pleased to have the opportunity to address the House Subcommittee on Energy Development and Applications this afternoon. The Engineering Experiment Station (EES) is the main research arm of Georgia Tech and presently has about 700 full time employees. EES has carried out many research programs benefitting Georgia's overall welfare in the past. The impacts of the "energy crisis" and the OPEC oil embargoes were quickly felt by many sectors of Georgia industry and the gravity of the situation was brought to the attention of EES personnel through the many industrial contacts that link EES and Georgia industry.

Georgia Tech became involved with the Georgia Office of Energy Resources (OER) in 1977 through the Industrial Energy Extension Service (IEES), a program which assists Georgia industrial plants in reducing their energy consumption. Working with OER and the Georgia Forestry Commission, it quickly became apparent that the most promising alternative energy resource available in Georgia was wood energy. Since Georgia contains over 24 million acres of commercial forest land, much of which is underutilized, the idea of using this resource to provide energy for Georgia businesses and Georgia industries had a lot of merit.

A wood energy conference was held in Atlanta in June 1977 by the EES and the Georgia Forestry Commission and over 250 interested people attended, many of them prominent representatives from Georgia industry. It was immediately obvious that the subject of wood energy was a topic that many people wanted to know more about, and Georgia Tech began searching for funding sources to develop wood energy programs, resulting in the projects which will be described in the following paragraphs.

### Past Wood Energy Programs

The Technology Applications Laboratory at Georgia Tech approached several governmental organizations in 1977 seeking funding for projects in wood energy research.

The first successful project was started in mid 1978 under the sponsorship of the Coastal Plains Regional Commission. This modest ($50,000) grant resulted in a publication entitled, "A Feasibility Study for Wood Energy Utilization in Georgia," which served as a reference document on the following subjects:

- o Wood availability in the eight Southeastern states
- o State-of-the-art of wood energy hardware
- o Future projections for wood energy markets
- o Projections of wood energy impacts on economy of the Southeast

The material assembled in this study provided new insights and directions into later Georgia Tech programs.

During the same time period, Georgia Tech and the Georgia Forestry Commission were successful in obtaining approximately $500,000 from the Georgia State Legislature to support a wood energy project. This activity was entitled "Industrial and Residential Wood Energy Demonstration Projects for Georgia," and resulted in the design and construction of two demonstration trailers for woodstove/central wood furnaces which were displayed around the state to re-educate Georgians on modern wood burning appliances. In addition, an industrial demonstration project at the Northwest Georgia Regional Hospital was begun. This project included a large wood gasification system which was first fired successfully on the site in Rome in 1980. Georgia Tech EES personnel acted as engineering advisors on this project.

In 1977, two additional hardware oriented wood energy projects were begun. A fireplace testing laboratory was built on the Georgia Tech campus to assess the efficiency of conventional fireplaces. This project was funded with money from the U.S. Department of Energy and a private brick manufacturer. Also, a poultry growout house in Carrollton, Georgia, was converted from a propane heating system to a wood heating system. This project was funded by the Georgia Poultry Federation.

In 1978, a $116,000 study entitled "Wood Energy Potential in West Virginia" was funded by the C.W. Benedum Foundation. This study met many of the same objectives for West Virginia that the earlier study for Georgia had met, including an assessment of the forest resources, a projection of the energy needs for the state that could be met with wood, and the probable impacts on the local economy of a new wood energy industry.

## Recent Wood Energy Programs

In 1979, the Office of Industrial Programs of the U.S. Department of Energy funded a research project entitled, "A Feasibility Study for Non-Conventional Fuel Use for an Industrial Integrated Energy System." This $190,000 project was completed in 1981 and resulted in a preliminary design and revenue projection for a wood fired cogeneration plant for the LaGrange Industrial Park in LaGrange, Georgia. This system would allow the industrial park tenants to replace their natural gas and oil energy requirements with locally available wood. This type of system could find similar applications in more than 150 sites in the State of Georgia alone.

In a companion study to the LaGrange project, a wood availability survey and preliminary system design for a wood fired steam plant for Fort Benning, Georgia, was completed in late 1981. If implemented, this project could allow the Army base to significantly lower its energy costs, becoming almost entirely self-sufficient in fuel for heating.

The Tennessee Valley Authority became interested in Georgia Tech's capabilities in the wood energy area based upon the work done with the fireplace laboratory and the woodstove trailers. Several projects have grown out of this interest including a project for training woodstove installation inspectors and a project for establishment of a "wood heater code information service." In addition, Georgia Tech has assisted TVA in performing feasibility studies for industrial sites.

In 1980, Georgia Tech and the American Cyanamid Company of Savannah were awarded a $150,000 grant to perform a study entitled, "A Feasibility Study of Production and Use of Wood Derived Fuels in a Large Chemical Plant." This work was funded by the Alternative Fuels Act, commonly known as Public Law 96-126. The study was completed in July 1981 and included an investigation of the application of commercially ready wood gasification and pyrolysis systems for the American Cyanamid plant. In addition to a preliminary design and technology assessment, the wood resources in the Savannah region were determined. This project has the potential to displace 2.2 million gallons of oil and 2.5 x $10^9$ cubic feet of natural gas per year in the Cyanamid Savannah complex.

Since there is no further federal funding for actually building such a gasifier system, Cyanamid has to take the next step on its own, and it appears that a Phase I wood gasification system will be under construction later this year.

A major program was recently completed for the Biomass Energy Technology Division at the U.S. Department of Energy. It was entitled, "A State Demonstration Program in Wood Energy," and was funded at a level of $793,000 for Phase I (1979-80) and $859,000 for Phase II (1980-81).

During Phase I, the project emphasis was to develop a definitive base of pertinent knowledge about the subject of wood energy and apply the information gathered to nonforest products industries. To accomplish the objective, four tasks were performed:

1. Economic Feasibility Studies. Eighteen feasibility studies were performed at interested plants. The feasibility studies addressed wood fuel availability and cost, system design, environmental concerns, and economics of implementation.

2. Demonstration Projects. Based on a systematic search, two nonforest industries were selected to participate in a cost-sharing construction program. These sites agreed to serve as

"showcases" for wood energy systems by installing actual equipment.

3. Wood Fuels Processing. This task assembled technical and economic data on wood to expedite the transition from petroleum fuels. Processing routes from forest to energy consumer were outlined.

4. Technology Transfer. This task served to overcome the lack-of-knowledge barrier to the commercialization of wood energy. Activities included seminars with detailed proceedings, two slide/tape programs, and a briefing report on industrial use of wood energy.

During Phase II, the project emphasis was expanded to include the five tasks described below:

1. Wood Energy Extension Service. This service was developed in a more formal manner to provide widespread technical assistance to industry. An additional 18 site-specific wood energy feasibility studies were carried out, and a detailed reference handbook on industrial wood energy use was published.

2. Demonstration Projects. The two wood energy demonstration projects begun in Phase I were completed in Phase II. Supervision continued on construction, start-up, and data collection.

3. Wood Fuels Processing. Specific problems of supply, storage, and drying of wood fuel delineated in Phase I were analyzed in-depth. Fuel property standards were better defined as well.

4. Wood Gasifier Applications. A survey of potential wood gasification applications in Georgia was carried out, as well as practical test programs on gasifier operation problems and product quality studies for a textile drying program.

5. Technology Transfer. Technology transfer was continued through seminars, publications, tours of demonstration sites, and presentations at national conferences.

Specific accomplishments achieved during the course of this project include the following:

- The conduct of 36 site-specific feasibility studies for new segments of industry that had not previously considered alternative fuels.

- The successful startup of two full scale wood-fired demonstration plants. These two plants represent a fuel savings of $1,130,000 annually for the two companies involved. 579 x $10^6$ cubic feet of natural gas and 56,000 gallons of No. 2 oil will be displaced annually.

- The in-depth analysis of many problems associated with storage, handling, and drying of wood fuels.

- The advancement of cooperation between an institute of higher education and industry.

- Further advancements in research into the production and application of low Btu gas from wood.

- A significant program of technology transfer including eight major seminars, several tours of demonstration sites, the production of audio-visual programs, and the dissemination of more than 45,000 copies of publications produced under this program.

The "State Demonstration Program in Wood Energy" has provided not only a detailed compilation of data and information on the use of wood as an energy source in nonforest products industries, but also a commercialization model that can be continued in the State of Georgia and emulated in other states.

During the course of this two-year program, a number of conclusions become apparent about the field of wood energy. These conclusions are stated below:

A. The feasibility studies performed show that the use of wood as an energy source for industrial plants and institutional applications can be economically favorable compared to the conventional use of natural gas and oil.

B. Wood waste was available in more than sufficient quantities at nearly all the sites studied.

C. There are a number of manufacturers offering equipment for the principal subsystems of storage, handling, boiler/furnace, and pollution control for the utilization of wood energy.

D. Wood was shown to be a viable, cost-effective energy source suitable for many nonforest related industries by the two demonstration projects built under this program.

E. The number of interested persons attending the dedication and tours of the demonstration sites indicated widespread interest in wood energy by many segments of industry.

F. Low Btu wood gasification is becoming a commercial technology. It is growing rapidly in forest product and nonforest product sectors. More low Btu wood gasifiers have been sold in the U.S. in recent history than coal gasifiers. The major advantages are no sulfur, very low ash, and low cost fuel.

G. The prime market for low Btu wood gasification is the retrofit of gas/oil boilers, kilns, and fired heaters. The next generation of equipment will be used for power generation via gas turbines or stationary diesel engines. These applications require a clean gas and more research is needed in gas cleanup before engine applications can be considered reliable technology.

H. A final frontier for gasification is the manufacture of medium Btu gas and synthesis gas for chemical feedstocks. This process is technically feasible, but will compete with coal and natural gas for the same market.

I. Further research is needed in low Btu wood gasification to refine the current equipment designs and broaden the field of application. The research includes gas composition, reaction kinetics, disposal of by-products, and effects of ash and other contaminants on combustion equipment.

J. Applications research is needed, with test firing of kilns and dryers to assess the potential for product degradation. These tests can be done with pilot plant equipment to avoid operational problems at industrial installations.

K. Detailed technical publications become a more popular method of technology transfer than seminars when industrial travel budgets tighten up during a recession.

L. An organized, well-defined technology transfer program can substantially enhance market penetration of a new technology.

M. The commercialization activities of the Biomass Energy Technology Division of the Department of Energy were quite effective in presenting the possibilities for wood energy conversions to industry through projects such as the one described in this paper. Widespread wood conversions have not been made in nonforest industries yet due to the present economic conditions, but it is probable that many more such conversions will be made in the near future.

## Further Research Needs

The Department of Energy has supported a number of good research and development programs related to the use of wood and biomass fuels since its inception, as have other agencies such as the Environmental Protection Agency and the U.S. Forest Service. It is our feeling, however, that much work remains to be done, and this work will not necessarily be done by the private sector alone, but will require the involvement of Federal and State governments. We at Georgia Tech feel that the following areas require expanded research programs:

- Further development of new processes to produce medium Btu gas from various biomass feedstocks. This work would build on research that is already underway.

- Further research needs to be done into the subject of gas cleanup for both low and medium Btu gases produced from biomass. This work would result in fuel gases with much wider application such as direct drying of minerals and textiles, and direct firing of internal combustion engines on a long term basis.

- There are certain aspects of pollution control which still need to be addressed for biomass fuels. These include assessment of $NO_x$ emissions from the burning of fuels containing high nitrogen content, methods for controlling these emissions, and assessment of air pollution emissions from wood/biomass gasifiers.

- Other environmental effects resulting from long term storage of biomass fuels (pile runoff, etc.) and more widespread harvesting of biomass fuels need to be addressed.

- Certain aspects of machinery development for fuel beneficiation (pelletizing, baling, etc.) still need major work, and some of the organizations working on this machinery could use monetary support and engineering support.

- Some areas of the country seem to have more than enough low grade biomass fuels available, but other areas could benefit from further work on "short rotation plantations." Activities in these areas should be continued.

- Agricultural residues are largely underutilized in many areas where open burning and landfilling still exists. There is much room for research in these areas involving harvesting methods, storage strategies, and methods of combustion.

- Institutional issues have still not been adequately addressed in some cases. What are the proper strategies for long term supply of biomass? Who will own and promote the construction of biomass energy production facilities?

- Continued tranfer of technology is very important. Developments of new processes in the U.S. that are directly transferrable to Third World countries will help our balance of payments as well as our prestige abroad.

If future Federal funding for renewable energy sources is completely cut off, many of the areas discussed above will not receive the attention they require. Most manufacturing companies are in the business of making a specific product and are somewhat afraid of adopting new systems which may affect their ability to produce. Also, developers of new systems are often undercapitalized and really need financial assistance to bring new ideas to completion.

In the cases of the wood energy plants that have been constructed or are under construction in Georgia such as the wood fired boiler at Integrated Products, the wood/peanut hull fired boiler at Gold Kist, and the wood gasification system at American Cyanamid, it is doubtful that these companies would ever have seriously considered these systems without the financial and engineering support of DOE and Georgia Tech.

Mr. HEITOWIT. We will now move to our next witness, Mr. Ray Shirley, director of the Georgia Forestry Commission, in Macon, Ga.

## STATEMENT OF A. RAY SHIRLEY, DIRECTOR, GEORGIA FORESTRY COMMISSION, MACON, GA.

Mr. SHIRLEY. Thank you, Mr. Chairman, and members of the subcommittee. It is a real joy to come and appear before your committee and tell you a little bit about what the State of Georgia is doing in biomass, particularly in the form of wood energy.

For the first time in many decades, wood is now economically feasible as a fuel for many industries, small businesses, and public facilities.

Today's prices for fossil fuels, coal, and other types of energy, have made wood a very economical fuel for many, many industries.

As recent as the late eighties, wood was a chief energy source in the United States. Even as late as the early thirties, we were using in my State, and throughout the Southeast—approximately 15 to 18 percent of all the energy being used in the homes was wood.

The fuel shortage and the embargo of oil in 1973 really focused our attention in Georgia and the Southeast, in particular, on another source of energy—wood.

One of the first things that came up as we began to try to promote wood for energy was, "Well, do you have enough? What are we talking about?" I could not even get anyone to listen, to even think that we had enough wood to be considered as a real major energy source in the United States.

I had known President Carter when he was Governor of Georgia. He grew up in Georgia, and I felt he knew, but I could not get anyone in Washington to believe that wood should be considered as a viable energy source or alternate energy source. When you realize that in the Southeastern part of the United States we have on the average of about two-thirds of the land area in in forests, that should tell us something about the amount of wood we have and the fact that we do have enough to consider.

When this oil shortage came into being, we began to talk with people that were having real concern over what could be found as an alternate energy source. We had some conferences around the State, with people at Georgia Tech, Bill Bulpitt and his staff, and found much interest in the use of wood. We saw a small gasifier demonstrated there, where wood was burned like natural gas, and with that idea we began to move forward to see what could be done.

Well, the first question, as I said, to be answered, was do we have enough wood.

I found that the U.S. Forest Service had never been asked the question by the Department of Energy or anyone else, how much wood is available in the form of wood biomass for energy? And so, with that, I went to them, and we worked up the biomass availability for the United States, as we had done for our own State of Georgia. We found that we had a total of approximately 7 percent, nationwide—wood that could replace other kinds of energy. The Department of Energy had not recognized this at all as an alternate energy source.

In Georgia, we have between 20 and 30 percent of wood that could be used as energy and not upset in any way our dependence upon the forest for all the other uses we have, and we are large users of the forest. We are the largest producer of pulp and paper in the Nation, one of the largest producers of lumber and plywood in the Southeast, and one of the largest in the Nation in that field.

Even so, we are producing 24 million cords of wood a year and we are harvesting only 14 million cords, leaving a surplus of 10 million cords that could be marketed.

In addition, most of our hardwoods are culls, and the only use and value they have is for energy, and so with that as a base, we began to see what we could do in the State to convince people of the fact that wood should be used as a source of energy.

As we began looking into the situation we found that in our pulp and paper industry 64.7 percent of their total energy need is now coming from trees. That is just one major industry. We have many more that are moving fast in this direction. The American Pulpwood Association provided us with these statistics.

We also had a question: Do you have the technology, and do you have the equipment to harvest this material in a form that could be used for energy? I can tell you today that we do have. We have mobile equipment, tree chippers, small bunchers, skidding equipment, live-bottom trailers and other forms of transportation with which we can move this biomass from the forest to the plant in a very economical way. The time has come when the use of wood as an energy source should be considered nationwide.

The legislature in 1978 appropriated $500,000 to the Forest Industry Commission to be used to develop wood for energy. We already had, and still have, a research department in the Forest Industry Commission. We were getting $400,000, so that gave us $900,000. We did not have any Federal commitments at that time, and it was some time before we received any Federal funds whatever. But we felt it was important that the Government and general assembly of our State would appropriate money for the research and development of wood as a viable alternative energy source. I think we have a lot of other States ready to do the same thing.

As a result our research, we found a lot of excellent spinoffs. One of the spinoffs was a biomass crude program where we worked with the U.S. Forest Service to devise a method to determine how many tons per acre of biomass material was available.

We knew commercial harvesters would want to know how much was there and what it was going to cost. A landowner would need to know its value, we developed a system that tells how many tons per acre, how many board feet, and how many cords of wood, and whatever other type of product that may be marketable. With that information, we are able to tell you exactly how many tons of residue is available from the logging industry.

We are harvesting 540,000 acres a year. We are leaving in the forest on the average of 22 tons which must be disposed of, and normally we have been piling it up and burning it, using energy to destroy energy in order to reforest the land.

Today, we are picking up that biomass. We are picking up 22 tons per acre, a valuable source of energy. We are now leaving the lands clear making it possible to reforest for 25 percent of what it cost before it was recovered in our biomass program.

We recently sponsored a Southeastern Wood Energy Conference jointly with the U.S. Forest Service in Rome, Ga., to discuss wood for energy and the technologies that we have for harvesting, processing and for combustion, into viable systems. The people attending wanted to know where to find the markets. We have the material, the equipment, and the technology; all we need now are customers to use the biomass and plants to convert from fossil fuels to wood.

As Mr. Bulpitt said, when we got some State money, we wanted to go into a number of combustion systems to see what could be done on an applied basis to convert a lot of industries in our State that are using fossil fuels to wood biomass.

You have to realize that if an industry, public utility or public agency, is using a boiler for fossil fuels, either coal or gas or oil, to replace that and to put in a wood furnace, they would have to replace the whole business if you have direct-fired wood. And so we were interested in wood gasification, where we could retrofit that boiler. We have thousands of them. If we could retrofit that boiler with wood gas, then we would not have to disturb a single thing except the retrofit.

The boiler would still be available to utilize what they had been using—natural gas, oil, or coal—as a backup. After some research, we were able to set up a 25-million-Btu-per-hour facility at one our State hospitals. It was the first one in the Nation to be installed. Georgia Tech was the engineer and consultant for the Commission and Applied Engineering of Orangeburg, S.C. had been awarded the contract and has worked with us.

The system is virtually perfect now, and we are very pleased with it. The second generation of that particular system has just been installed in Florida by the Florida Power & Light Co. We believe it is an alternate source of energy that is going to be heard from in the future, because it will not entail such a high capital outlay to convert from the system now being used, to wood, and still they would be able to retain a backup should they need it.

Now, this money that the general assembly appropriated, the $500,000 in 1948, the $400,000 each year since that time, including the current year, and the year beginning July 1, has to be accounted for every year. We have been pleased to report that we have installed different combustion systems into a variety of State facilities, from hospitals to prisons, to schools, to other facilities in the State, to show how the present system of fossil fuels can be converted to wood as an energy source.

Last year, the legislature appropriated $2.2 million to convert a prison system that had 22 little individual energy systems with one central system, now those 22 systems have natural gas. We are in the process of the $2.2 million conversion, to a wood-direct system. The legislature has also appropriated $5 million recently to install a wood system at the State hospital in Minnixville, Ga.

Wood is a viable alternative source. Biomass is here. It is a viable renewable system, we can grow twice the timber we have today if there is a demand.

Now, what do we need to do? The Commission's hope is to determine the resources available on a continuing basis. We have continued that with various studies attached here. We also want to demonstrate, as in combustion systems on the market, for schools and hospitals, prisons, large and small industry use. We have many industries waiting right now to see what we can do.

To sum up, we have made a film on wood energy in Georgia that has been well received throughout the United States on what is happening in wood research and development, I would also like to mention one other project just to show you how this energy source has also become useful in homes. In 1979 we made a survey and found there were 800,000 cords of wood being used in homes. We made another survey in 1981 and we found 1,831,000 cords of wood were for home use. We found one out of every four homes in Georgia using wood to some degree as a source of energy.

We have worked with a lot of different companies and organizations and industries and want to give credit to them for their valuable contributions: the Georgia Institute of Technology, Tennessee Valley Authority, U.S. Department of Energy, Appalachian Region Commission and others. In conclusion, we think the greatest needs from our standpoint in wood is continued research to perfect wood gasification to convert presently existing boilers that are now using fossil fuels.

No. 2, we feel that energy tax incentives of 20 percent should be used when converting from fossil fuel to biomass or coal. We think this would encourage the maximum conversion of the use of fossil fuels to this available energy source in the United States. This could be accomplished at a minimum cost to the Federal Government since it will not involve appropriated funds or an expanded bureaucratic budget.

I appreciate the opportunity of being here today and will be pleased to answer any questions.

Thank you.

[The prepared statement of A. Ray Shirley follows:]

# WOOD ENERGY RESEARCH AND DEVELOPMENT PROGRAM

## GEORGIA FORESTRY COMMISSION

By

Ray Shirley, Director

For the first time in many decades, wood is now economically feasible as a fuel for many industries, small businesses and public facilties. Today's prices for coal, oil, gas and electricity makes wood the most economical fuel available for many uses.

In the late 1880's, wood was the chief source of energy in the Nation. Coal and electricity replaced wood as the chief energy source; however, in Georgia and the South in the mid 30's wood for heating and cooking utilized 15 to 18 percent of the annual consumption of wood in the South.

The fuel shortage and oil embargo of 1973 focused attention on the basic resources essential to the well-being of the United States.

The outlook for fossil fuels and other non-renewable resources has been studied and intensively evaluated. However, wood, a renewable and expandable resource, has received little attention in spite of its current importance to industry and its potential for the future.

Georgia and the Nation's forests offer a renewable and expandable economical fuel--one that could greatly reduce our dependence on foreign and other domestic sources for energy fuel.

The Georgia Forestry Commission has made studies and collaborated with the U. S. Forest Service on the amount of forest raw material available in Georgia (see Attachment A).

The South is particularly suited to wood energy technology, because its fast growing forests are capable of being replenished on the average of every 25 to 30 years. In Georgia, it is estimated that 20 to 30 percent of the total energy used annually could be reaped from the forests. For the Nation, seven percent of the total energy needs could be annnually supplied from forest waste and low value tree species. This would leave the more valuable hardwoods and softwoods, and improve forests production and aesthetics. A considerable savings can be realized once the conversion from gas or fuel oil to wood is completed. Several industrial facilities in Georgia which have converted to wood will pay for the new equipment in five years or less.

Currently, Georgia is growing 24 million cords of wood annually, or approximately one cord per acre. Tree removal amounts to 14 million cords from 540,000 acres annually. Our research shows that on the average, 22 tons of logging residue per acre remains following the logging operation. With 8 million BTU's available per ton, our logging waste offers a great opportunity for fuel if all the forest products are harvested in one operation in conjunction with a total tree harvester.

Many low quality (cull type trees) forest areas will produce from 60 to 100 tons of wood for energy per acre. Some acres will have as much as 120 to 140 tons of biomass for energy.

Wood energy systems have been in widespread use in the forest products industry for several years. The American Pulpwood Association indicates that today 64 percent of all energy used by their industry in Georgia comes from the forest in the form of bark, residue, whole tree chips and spent liquors from the pulping process. In other sectors, ready supplies of previously available and cheaper petroleum fuels made wood energy systems unattractive. Also achieving widespread wood energy use requires simultaneous development of harvesting, fuel processing and wood combustion techniques.

The technological developments in forest harvesting equipment, including small whole tree chippers and equipment to economically harvest cull wood and small trees, opened up an entire new supply of wood material previously wasted. The whole tree chipper can be readily moved within close proximity of the felling operation which makes possible the harvesting of the total tree from one inch in diameter and up.

With the advent of the small, highly mobile tractors equipped with shear and feller buncher, high speed rubber-tired skidders with hydraulic grapple, harvesting of this heretofore unmerchantable wood is commercially feasible. Mechanical equipment can be used to thin crowded stands and unmerchantable timber and leave the stand in a condition for quality timber growth without damage to the remaining trees. In many cases total tree harvesting will permit areas to be planted without additional site preparation. Reforestation costs can be reduced 50 to 75 percent, depending on the terrain.

There are a growing number of forest industries using all of their wood waste and generating most of their energy needed to operate their plants. Equipment is now available to utilize sawdust, bark, chips and mill waste in an efficient automative manner that meets environmental standards. Only four percent of our forest processing plant residue is not being utilized in Georgia at the present time.

There are commercial logging companies and raw material suppliers that are producing total tree chips and residue for industrial fuel. This can be delivered on a contract basis to industries that have converted to wood for fuel.

At a Southeastern Wood Energy Conference, sponsored by the U. S. Forest Service, and the Georgia Forestry Commission in May 1982, a representative of Georgia Timberlands, a company which operates a large total tree harvesting operation, indicated that markets for wood fuel were badly needed (see Attachment B). At present, wood fuel producers have a very restricted market to sell the wood fuel. If markets for this natural resource are developed, the timber harvesters can readily meet the demand for wood fuel.

There is a significant potential for economic development and employment if wood energy can be developed. The jobs created by developing another market for our natural resources will be significant. The income to individuals who will have a new market for previously useless wood waste (energy previously destroyed) will provide additional economic benefits. It is in the best interest of the State and Federal government to provide the required leadership through demonstration projects and incentives for developing all aspects of wood energy systems.

Energy wood promises to become an alternate fuel, thereby keeping many plants and businesses open in periods of petroleum fuel scarcity. Wood is presently being used as the primary fuel in several schools, institutions and industries in Georgia. The existing oil and gas systems are being retained as back-up fuel systems. Wood also offers the potential of a wood market to some areas where such markets are poor or non-existent. A third economic advantage is that loggers and wood producers may find that the harvest of energy wood gives them a greater degree of protection against loss of income from quota restrictions, mill shut-downs or market slumps.

Wood residues, unmerchantable wood in cut-over and well stocked stands and poor quality hardwood trees are available in abundance. The technology is available to utilize them efficiently, and the economics would justify the prospect of conversion even if there were not an energy crisis.

What is being done in Georgia to re-establish wood as a primary energy source? The Forestry Commission, Georgia Institute of Technology Research Division and others have pooled their resources for several years to promote wood as an alternate energy source.

The Georgia General Assembly supported by Governor George Busbee, appropriated $500,000 to the Forestry Commission in 1978 for a wood energy research and demonstration program to promote the use of wood for energy throughout the state. Four hundred thousand dollars has been appropriated in 1979, 80, 81 and 82. Two other designated appropriations of 2.2 million (in 1981) and 2.5 million (in 1982) dollars have also been approved for two state facilities to be converted from oil and natural gas to wood energy.

The Forestry Commission has approached the wood energy endeavors in three areas:

1. To determine that the forest resource is available on a continuing basis for wood energy.
2. To assist in developing harvesting and utilization systems to supply the low quality material for wood energy.
3. To demonstrate the combustion systems on the market for residential, school, hospital, prison, and small and large industry use (see Attachment C).

Based on the state's energy program, some financial assistance has been received from the U. S. Forest Service, Tennessee Valley Authority, Department of Energy and the Appalachian Regional Commission.

The Forestry Commission has conducted 28 demonstrations across the state to show landowners, timber harvesters, industrial leaders and others how to harvest all the trees on an area for the most valuable forest product. The more valuable product is selected and placed on log trailers before the tops and poorer quality trees are processed through the total tree chippers.

Through applied research by the U. S. Forest Service and the Forestry Commission, a biomass cruise program using computers has been developed to determine the tons per acre of biomass on a particular area. This will enable the commercial total tree harvester to determine the volume per acre and the landowner to know what his low quality timber is worth for biomass.

Reforestation on privately owned forests will greatly increase if it can be accomplished by removing 60 - 140 tons of total tree biomass per acre, which will pay for establishing the new crop of a desirable type tree. Since much of the site preparation cost will be eliminated by removing all trees down to a one-inch diameter, the property owner will have to invest very little or none of his money above the sale of the biomass for energy.

Residential use of wood heat has doubled in Georgia during the past two years. In 1979, 800,000 cords were utilized for home heating; and in 1981, this increased to 1,631,618 cords (see Attachment D).

What research and development programs are needed from the Federal Government to expand the use of biomass for energy?

1. Funds for research to perfect wood gasification and similar systems to convert present or existing boilers that are now using fossil fuel. The potential is great in this area and will minimize the expenditures in converting to a renewable energy source.
2. An energy tax incentive of at least 20 percent in converting from fossil fuel to biomass or coal. This would encourage the maximum conversion from the use of fossil fuels to an available energy source in the United States. This can be accomplished at a minimum cost to the Federal Government since it will not involve appropriated funds or an expanded bureaucratic budget.

ATTACHMENT "A"

## GEORGIA'S WOOD AVAILABLE FOR ENERGY

By
Druid N. Preston
Chief, Forest Management
Georgia Forestry Commission

One of the first questions we encountered in our wood energy program in Georgia was: Do we have a sufficient wood supply in Georgia to even merit discussing wood for use as an energy source? We had anticipated this question and obtained facts on the wood resources available for energy. This was accomplished with the information provided by Joe McClure and his staff at the Southeastern Forest Experiment Station in Asheville, North Carolina.

Many people were concerned that this new use of wood would drive up prices, deplete the forest, and offer competition to existing wood-using industries. We were quick to emphasize that wood to be used for energy would be the cull timber, undersized stems, and residue from logging and processing. The governor of our state was concerned about the above. After facts were presented, these questions were resolved, and I believe we dispelled any doubts as to the type of wood we were advocating for use as energy.

The next question we encountered was: This should be done, but how can you get this material harvested? The above question was answered through some 28 whole tree chip harvesting demonstrations conducted over the state -- with greatest concentration in the northern two-thirds of the state. There are at present some 14 producers that operate 31 whole tree chip harvesters in the state. The harvesting system is in place to convert wood to energy.

In addition, we made a detailed study and analysis of biomass in Georgia by actually cruising the biomass of a 50-mile radius of LaGrange, Georgia. This study was for the purpose of establishing a co-generating system for the City of LaGrange.

The same type of study was conducted for Nuclear Assurance Corporation of Atlanta for a wood alcohol (ethanol) plant at Roberta, Georgia.

An analysis and study was made under contract to Georgia Tech for the Department of Defense at Fort Benning, Georgia. This was for the purpose of determining if sufficient wood was available on federal property (military reservation) to sustain a wood energy system for Fort Benning. This system would use garbage and wood as fuel. An interesting aspect of this analysis is the type of system that is being proposed. The wood supply available from the military lands would support the system for 250 years even if no wood was grown to replace what had been removed (14,000,000 tons available).

All of the areas could sustain the above wood energy systems with ease using only residue, cull wood, and waste from logging operations.

Based on average biomass per acre for Roberta, Georgia, 112 tons per acre, operating on 40 weeks per year, would require 15,200 acres per year out of 3.5 million acres of forest, or less than one-half of one percent of the area to sustain this plant. This does not take into account the use of residue.

Along with our biomass studies and analyses, the Commission, in cooperation with the Forest Service, has developed a total biomass timber cruise program. This is a computerized program that encompasses all conventional timber products as well as biomass - board feet, cords of pulp, fuel wood, etc. Present example of biomass timber cruise summary Table 4 (Exhibit 1).

We recognized a need to develop a timber cruise system that would accommodate all types of harvesting systems including whole tree chips and firewood. We have this system in place and operational. All foresters have been trianed in the entire process including accessing the computer by use of terminals. In addition, we have secretaries trained to also use program.

This program was actually a spin-off of the Commission's wood energy program, and we feel the system will provide another dimension to the approach of better utilizing the forest and as an inexpensive method of regenerating the forest.

In summary, wood is available for wood energy in Georgia in quantities to sustain energy needs of many industries. The landowner ownership and patterns of ownership make this possible. Wood owned by non-industrial private individuals is available. At times, some forest industries become concerned over a supply of wood for a particular mill. This supply problem is not due to availability of wood in sufficient quantities. It is due to harvesting problems (weather, management, etc.), low stumpage prices, etc. Most mills have frequent quota limits due to oversupply of wood. The quotas are most frequent and are of long duration which usually handicaps timber harvesters and make for less efficiency in harvesting operations. In using wood for energy, hopefully, this will provide an additional market, utilize all forest to the highest means possible, and provide a low cost alternate method of regeneration.

(EXHIBIT 1)

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           TOTAL BIOMASS CRUISE PROGRAM---GEORGIA FORESTRY COMMISSION

LANDOWNER - WILLIAM MANNING
ADDRESS -   MACON GA.                                 CASE NO.- 1
LOCATION -  WASHINGTON CO GA                          DISTRICT NO.-        18
FORESTER -  PRESTON                                   TRACT SIZE(AC) -  958.00
ADDRESS - MACON                                       PHONE - 744-3241
                                                      DATE -  81/06/19.

TABLE 4--SUMMARY OF PREDICTED TOTAL TREE AND TREE COMPONENT WEIGHT AND VOLUME.
                         ESTIMATED TOTAL YIELD FOR TRACT
-------------------------------------------------------------------------------

 COMPONENT                    PINE        H-HARDWOOD      S-HARDWOOD     ALL TREES
-------------------------------------------------------------------------------
                          GREEN TONS OF WOOD AND BARK
                          ---------------------------
TOTAL TREE(ALL)              24534.1        34255.3           0.0          58789.4
SAPLINGS(< 5 IN.)             2200.1         4999.1           0.0           7199.2
TOTAL TREE(>= 5 IN)          22334.0        29256.2           0.0          51590.1
TOTAL STEM TO 4 IN TOP       17873.5        20003.9           0.0          37877.3
   SAWLOGS-1                  7048.4         6005.0           0.0          13053.4
   PULPWOOD (ALL)            10825.0        13998.9           0.0          24823.9
      PULPWOOD TREES          9112.9        11961.2           0.0          21074.1
      SAWTIMBER TOPS          1712.1         2037.7           0.0           3749.8
TOTAL CROWN                   4460.5         9252.3           0.0          13712.8
   CROWN FIREWOOD>=2IN         508.5         4709.2           0.0           5217.6
   CROWN FIREWOOD>=4IN           0.0          635.2           0.0            635.2
                          CORDS OF WOOD AND BARK-2
                          ------------------------
TOTAL TREE(ALL)               8762.2        12019.4           0.0          20781.6
SAPLINGS(< 5 IN.)              785.8         1754.1           0.0           2539.8
TOTAL TREE(>= 5 IN)           7976.4        10265.3           0.0          18241.7
TOTAL STEM TO 4 IN TOP        6383.4         7018.9           0.0          13402.3
   SAWLOGS-1                  2517.3         2107.0           0.0           4624.3
   PULPWOOD (ALL)             3866.1         4911.9           0.0           8778.0
      PULPWOOD TREES          3254.6         4196.9           0.0           7451.5
      SAWTIMBER TOPS           611.5          715.0           0.0           1326.4
TOTAL CROWN                   1593.0         3246.4           0.0           4839.5
   CROWN FIREWOOD>=2IN         181.6         1652.3           0.0           1833.9
   CROWN FIREWOOD>=4IN           0.0          222.9           0.0            222.9
                        SAWLOG BOARD-FOOT VOLUME--(MBF)
                        -------------------------------
SAWLOGS (SCRIBNER)             823.5          737.0           0.0           1560.5
-------------------------------------------------------------------------------
1- SAWLOG MERCHANTABLE TOP: 7-INCH DOB FOR PINE, 9-INCH FOR HARDWOODS OR THRU
   LOG GRADE NUMBER 3 MERCHANTALITY
2- POUNDS PER CORD: PINE =5600., SOFT HARDWOOD =5700., HARD HARDWOOD =5700.
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## ATTACHMENT "B"

# WOOD ENERGY - A FOREST MANAGEMENT TOOL FOR SMALL LANDOWNER

Holiday Inn
Rome, Georgia

May 18-20, 1982

### MONDAY - MAY 17

Evening - Arrival, Holiday Inn, 707 Turner McCall Blvd., Rome, GA

6:30 - 7:30 - Registration, Holiday Inn

### TUESDAY - MAY 18

7:30 - 8:00 - REGISTRATION

MODERATOR - John Mixon, Georgia Forestry Commission

8:00 - 8:30 - WELCOME AND OPENING COMMENTS
A. R. Shirley, Director, Georgia Forestry Commission

8:30 - 9:00 - WOOD ENERGY FILM - Georgia

9:00 - 9:45 - ECONOMICAL FEASIBILITY OF USING WOOD FOR ENERGY
A. B. Curtis, U. S. Forest Service

9:45 - 10:15 - BREAK

AVAILABILITY OF POOR QUALITY STANDS FOR WOOD ENERGY IN THE SOUTHEAST
10:15 - 11:00 - Druid N. Preston - Georgia Forestry Commission
11:00 - 11:30 - Tom Morgan - North Carolina Division of Forest Resources

11:30 - 12:00 - MARKET POTENTIAL FOR WOOD CHIPS AS AN ENERGY SOURCE
Glen Plummer, Georgia Kraft

12:00 - 1:00 - LUNCH

1:00 - 1:30 - ECONOMICS OF FOREST MANAGEMENT ON SMALL WOODLANDS
J. D. (Red) Strange, Consultant & Dr. Albert Montgomery, Georgia State University

HARDWOOD MANAGEMENT:
1:30 - 2:00 - Intermediate Stand Management
Frank Shropshire, U. S. Forest Service

2:00 - 2:30 - Natural Regeneration
Tom Cambree - Alabama Forestry Commission

2:30 - 2:45 - BREAK

2:45 - 3:15 - FUEL HANDLING--TRANSPORTATION AND STORAGE
Phil Welling, Peerless

TECHNIQUES OF COMBUSTION

3:15 - 3:40 - GASIFICATION - Jim Jackson, Applied Engineering Company

3:40 - 4:05 - GRATE SUSPENSION FIRING IN SMALL INDUSTRIAL BOILERS
Welch Goggins, Industrial Boiler Company

4:05 - 4:30 - FLUIDIZED BEDS - Robert Lightner, York-Shipley

## WEDNESDAY - MAY 19

Field Trip - depart Holiday Inn 8:00 a.m.

8:30 - 9:30 - Integrated Products

10:15 - 11:30 - Total Tree Chipping Demonstration

12:00 - 1:00 - Box Lunch

1:00 - 2:00 - Gasification - N. W. Georgia Regional Hospital

2:15 - 3:00 - Fairbanks Industry

3:30 - 4:15 - Storey Lumber Company

4:30 - 5:30 - Field Plots

6:00 - Return to Holiday Inn

Evening - 7:30 - 8:00 (Optional) - Preview of new residential wood energy movie, "A Stoveside Chat with Ben Franklin"

## THURSDAY - MAY 20

MODERATOR - Joe Saucier, U. S. Forest Service

8:00 - 9:00 - TOTAL BIOMASS CRUISE PROGRAM
Alex Clark, U. S. Forest Service

9:00 - 9:30 - CHEMICAL TREATMENT FOLLOWING TOTAL TREE HARVESTING SITE PREPARATION TO RELEASE PINE SEEDLINGS
Ansel Miller, Clemson University

9:30 - 10:00 - EFFECT OF WOOD ENERGY HARVESTING ON SOILS AND NUTRIENTS
Wade Nutter, University of Georgia

10:00 - 10:15 - BREAK

10:15 - 10:45 - FIREWOOD - AN INCENTIVE FOR SMALL LANDOWNERS
Fred Allen, Georgia Forestry Commission

INDUSTRIAL APPROACH TO TOTAL TREE HARVESTING FOR SITE PREPARATION ON PRIVATE LANDS:

10:45 - 11:15 - Georgia Timberlands - Terrell Green

11:15 - 11:45 - Westvaco - Carol Douglas

11:45 - 12:00 - Questions

12:00 - 1:00 - LUNCH

1:00 - 2:00 - FINAL WRAP-UP AND DISCUSSION

## ATTACHMENT "C"

## GEORGIA WOOD ENERGY PROJECTS

Georgia Forestry Commission Installations:

1. Northwest Georgia Regional Hospital, Rome: 25 million BTU/hr. gasifier is operating. We had our best month in October 1981 saving $10,800 with wood over the cost of natural gas. We are continuing to have our "ups and downs" with this system.

2. Franklin County High School, Carnesville: A 3.3 million BTU, 100 h.p. wood unit is operating. System is working well.

3. Treutlen County High School, Soperton: A 3.3 million BTU, 100 h.p. wood unit is completed. System tested; working well. Dedication April 7, 1982.

4. Mt. View School, LaFayette: A 1.6 million BTU, 50 h.p. wood unit is completed. System is being checked out and will be ready for next heating season.

5. Middle Georgia Correctional Institution, Chester: A 6.6 million BTU, 200 h.p. wood unit is being installed. Should be in operation next heating season.

6. Union County High School, Blairsville: A 500,000 BTU wood unit is in operation.

7. A 3.3 million BTU, 100 h.p. wood unit is being used as an agricultural crop dryer to dry corn and soybeans. It has also been used to heat a poultry house. The system was used this season to dry pine cones with a savings of $2,000.00 over natural gas.

8. Walker County Correctional Institution, LaFayette: A 4.9 million BTU, 150 h.p. wood unit is being installed.

9. Georgia Industrial Institute, Alto: A 30,000 pound per hour steam system is being installed to replace 23 separate boilers at the prison. Wood chips will be used for fuel.

10. Funds have been appropriated to install a wood system at the Central State Hospital in Milledgeville, Georgia. The system will cost $2.5 million, but will have a payback of 4.1 years.

11. An experimental residential wood chip furnace is being installed in our Rome district office. This unit will use wood chips and will generate 80,000 BTU.

12. Westside Elementary School, Whitfield County - A wood system is planned to heat the school. A 50 h.p. wood system to be completed by next heating season.

13. Forestry Center, Macon, Georgia - A 100 h.p. wood chip system is planned to heat the Commission offices as well as the U. S. Forest Service offices located on the complex.

Other Installations (not including pulp and paper and sawmills):

1. Armstrong Industries, Macon - A fluidized bed combustor, utilizing five tons of green chips per hour, has replaced one million cubic feet of natural gas. They have the second unit on line with the third unit going on line in the spring of 1982.

2. Burlington Industries, Rabun - A wood system, utilizing 400 tons of wood residue per day, is operational. It replaced an oil system that used 18,000 gallons of oil per day.

3. Fairbanks Industries, Rome - A 300 h.p. wood system has replaced an oil unit that used 90 gallons of oil per hour.

4. Integrated Products, Aragon - A 400 h.p. wood system has replaced an oil unit that used 120 gallons of oil per hour.

5. Goldkist, Valdosta - A 60,000 pound per hour steam system using wood chips and nut hulls.

6. Mathis-Akins, Macon - A 100 h.p. wood chip system used to cure concrete blocks.

7. North Georgia Electric Membership Corporation is installing a 30 h.O. wood system in their office at Dalton to heat their headquarters. Wood chips or wood residue will be used as fuel.

8. Truett-McConnel College, Cleveland - Has installed a new type stick wood system in the president's home. The hot water system will supply domestic heat and hot water for this home.

9. Southeast Georgia Fuel Ethanol Distillery, Douglas - 319 h.p., 11,000-pound steam per hour wood system.

10. Fort Stewart - An 80,000 pound per hour steam system using wood. To be operational in June 1983.

11. Proctor & Gamble, Albany - 100,000 pound of steam per hour, replaces oil as the primary fuel.

12. Roberta Gasahol, Nuclear Assurance Corporation, Roberta - 1,000 h.p. boiler being installed.

Copies of Forestry Commission research publications on wood energy are included in back of folder:

1. Wood Energy in Georgia
2. Wood Gasification--A Unique Method of Extracting Energy from the Forests of Georgia
3. Whole Tree Chipping...A Forest Management Tool
4. A Test of Prediction Equations for Estimating Hardwood Understory and Total Stand Biomass
5. Wood as a Household Energy Source in Georgia
6. Estimating Quantities of Windrowed Forest Residues...A Management Tool for Increased Biomass Utilization
7. Industrial Wood Combustion Systems
8. Cruising Procedures for Estimating Total Stand Biomass
9. Energy Wood Harvesting - A Study of Promises and Pitfalls
10. The Firewood Industry in Georgia - A Study of its Characteristics and Needs
11. TBCP--A Computer Program that Estimates: Total Tree Chips, Saw Logs, Pulpwood and Firewood
12. Total Tree and Firewood Weights and Volumes of Scrub Oaks in the Georgia Sandhills
13. Creosote Production from Beetle Infested Timber
14. The Pulp and Paper Industry and Georgia's Forest Resource: An Economic Outlook

## ATTACHMENT "D"

## FIREWOOD FACT SHEET
## GEORGIA 1981

| | |
|---|---|
| Percentage of homes using firewood in 1981 | 33.4% |
| Percentage of homes using firewood in 1979 | 25.7% |
| Increase in last two years | 30% |
| Number of homes using wood in 1981 | 674,411 |
| Number of homes using following equipment: | |
| 1 fireplace | 405,321 |
| 2 fireplaces | 33,720 |
| 3 or more fireplaces | 9,441 |
| 1 fireplace insert | 72,836 |
| 2 fireplace inserts | 2,698 |
| 1 free-standing stove | 203,672 |
| 2 free-standing stoves | 8,093 |
| 1 central wood furnace | 8,093 |
| Percentage of fireplaces that have glass screens | 36.6% |
| Average cords firewood per using home in 1981 | 2.7 cords |
| Average cords firewood per using home in 1979 | 2.2 cords |
| Average cords for all households in 1981 | .81 cord |
| Average cords for all households in 1979 | .55 cord |
| Total cords used in Georgia in 1981 | 1,631,618 cords |
| Total cords purchased | 287,165 cords |
| Total cords cut by user | 1,344,453 cords |
| Percentage of wood purchased | 17.6% |
| Percentage of wood cut by user | 82.4% |
| Average cost per cord of purchases wood | $79.82 |
| Total value of purchased wood | $22.9 million |
| Implied value of wood cut by user | $107.3 million |

Proportion of home heat supplied by wood:

| | Number of Homes |
|---|---|
| 25 percent or less | 314,950 |
| 26 to 50 percent | 120,720 |
| 51 to 75 percent | 76,883 |
| 76 to 100 percent | 161,858 |

| | |
|---|---|
| Percentage of all homes that plan to install new wood burning equipment | 20.2% |
| Number of homes that plan to install new wood-burning equipment | 407,577 |

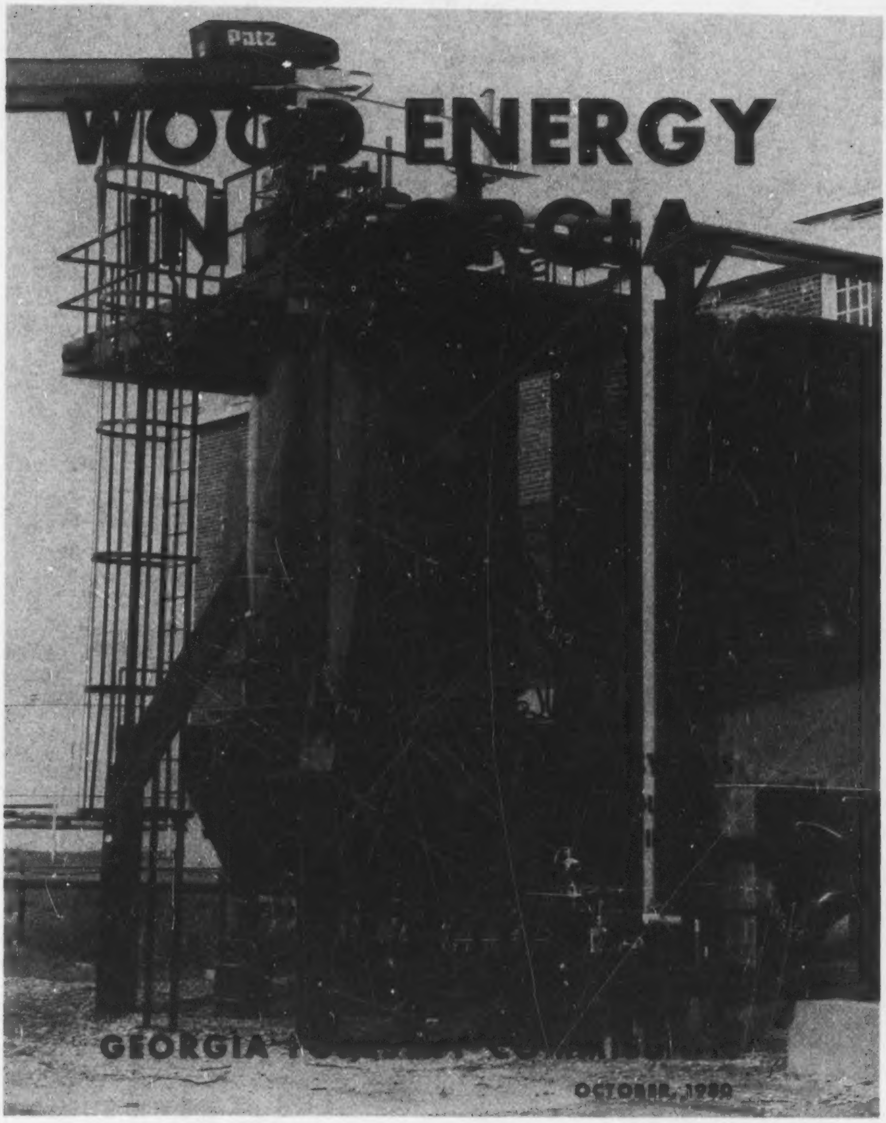
Type of new wood-burning equipment to be installed:

| Type of Equipment | Number of Homes |
|---|---|
| Open fireplace | 133,169 |
| Fireplace insert | 104,921 |
| Free-standing stove | 159,399 |
| Central wood furnace | 18,159 |

## BIOGRAPHICAL SKETCH

Arthur Ray Shirley
Director
Georgia Forestry Commission

| | |
|---|---|
| PERSONAL: | Born Hart County, Georgia |
| EDUCATION: | Graduated University of Georgia, B.S. Forestry |
| BUSINESS: | U. S. Forest Service, 1 year; Georgia Extension Forester and Naval Stores Specialist, 11 years; State Forester, Georgia, 1947-49; General Manager, American Turpentine Farmer's Association Cooperative, Valdosta, 1949-60; Director, Georgia Forestry Commission, January 20, 1960 to date. |
| SERVICE: | World War II, Captain Corps of Engineers |
| OFFICES: | Chairman, Forestry Non-Point Source Technical Task Force; Member, State Water Quality Management Planning Policy Advisory Board; Member, Coastal Zone Management Council; Member, Society of American Foresters Task Force on Forest Biomass as an Energy Source; Former Member, Georgia Forest Research Council and State Board of Registration for Foresters; Past President (1966-67), National Association of State Foresters |
| ORGANIZATIONS: | Society of American Foresters, Georgia Forestry Association, National Association of State Foresters, American Forestry Association, Soil and Water Conservation Committee, Georgia Farm Bureau, Soil Conservation Society of America |



WOOD ENERGY
IN GEORGIA

GEORGIA FORESTRY COMMISSION

OCTOBER, 1980

# INTRODUCTION

The 1973 oil embargo by the OPEC Countries, combined with extreme weather in January and February of 1977, caused a severe change in energy supply and demand situations. Wood energy had not been considered an alternate fuel source since fossil fuels were relatively cheap and available. In the winter of 1977, natural gas and heating oils were in short supply. Eighty-three industries and/or businesses in Macon were closed from a few days to weeks due to fuel shortages. Similar conditions existed in the northern half of the state.

The Forestry Commission and Georgia Tech Experiment Station invited business leaders to meet and explore wood for energy. The Commission had inventoried the state wood supply and determined an enormous quantity of forest biomass was available. A model of a gasification system using wood chips was demonstrated and wood stoves and heaters were displayed and promoted.

Governor George Busbee and the General Assembly appropriated $500,000 to the Commission for wood energy effective July 1, 1978, an equal amount on July 1, 1979, and $400,000 on July 1, 1980.

Through a research study, a method of inventorying a timber stand in tons per acre was developed. Wood harvesting equipment has been tested and proven effective to harvest sawtimber, peeler logs, poles, pulpwood, and energy wood chips in the same logging operation.

A wood gasification combustion process has been installed and is now operating at the Northwest Georgia Regional Hospital at Rome. A 500 h.p. boiler was retrofited to burn wood gas produced from whole tree chips with a maximum 65 percent moisture content. The gas is piped to the burner in the boiler and replaces oil and natural gas. It is the largest gasification system using green chips that we know of in existence. It is automatically operated and has a three-and-a-half day fuel storage supply system.

Another major development is the agricultural crop dryer now ready for commercial use. It uses whole tree chips (green) for fuel; is automatically operated using electric current existing on the farm; and can dry all kinds of grains, soybeans, and other crops with the exception of tobacco and peanuts. Hopefully, it can be modified to cure tobacco.

A new automatic fuel chip system has been installed in a junior high school at Blairsville, Georgia. It is now operating and has replaced an oil system.

The Commission employed Georgia Tech Experiment Station as consultant for the gasifier. Commission personnel have been responsible for the agricultural dryer, the school systems, and other activities. Two additional school systems have wood chip facilities under construction. One replaces oil and the other electricity. The new Correctional facility in Dodge County will have a wood chip system, and $200,000 has been alloted for it. Other state facilities are being investigated and data collected for wood energy application.

—A. Ray Shirley, Director
Georgia Forestry Commission

# THE SOURCE

## IT ALL STARTS IN THE ABUNDANT FORESTS THAT BLANKET THE STATE

Georgia has 24 million acres of commercial forest land. Presently, the growth amounts to approximately 24 million cords annually. Tree removal amounts to 14 million cords on 640,000 acres annually, leaving a surplus of 10 million cords.

On the average, 22 tons of waste per acre remains in the forest from logging operations. A cord of wood is equivalent to 3.3 barrels of oil for energy use. Another 35 million cords of cull trees are in the forest that are not merchantable unless used for energy. If 25 percent of the logging waste, excess growth and cull trees are used for energy, they would replace 42.5 million barrels of oil annually, representing a value of over $1 billion. This will be a major source of fuel for industry, institutions, schools and other businesses in the state.

The Forest Management Department of the Commission has detailed data on the above assumptions.

The Forestry Commission has conducted ten harvesting demonstrations in north and middle Georgia. A publication by the Research Department of the Forestry Commission explains the whole tree chipping process (Research Paper No. 4). Twenty-nine operators are presently using total tree harvesting machines in Georgia.

Detailed forest field studies have been conducted by the Commission and the U. S. Forest Service to determine the tons per acre of the biomass or the total tree chips. Volumes from 70-80 tons per acre are common on the test sites. Some areas of cull hardwoods are producing 100 tons per acre or more. Some studies have been conducted concerning storage and hauling wood chips.

Removing the low grade hardwoods is a tremendous benefit to the forest owner. Average cost for heavy mechanical site preparation in Georgia is $135 per acre plus $44 for mechanical tree planting, including trees. The site preparation can be eliminated by using total tree harvesting.

Certain total trec harvesting operations are taking every stem down to one-inch diameter. This is excellent site preparation for the establishment of a desirable stand of trees. Instead of having the above expense, the landowner can actually receive a profit by carrying out this type site preparation.

*A forester, at left, examines a cull tree that could be harvested for wood energy purposes. The scene above is a small portion of the 24 million acres of forests that play a tremendous role in the economy of the state.*

The Commission has established several one-acre study plots to demonstrate the various methods of harvesting and improving timber stands. Located on property of Berry College, the plots are visited by timberland owners and other interested persons.

Commission personnel serve as guides to point out the advantages of certain practices made on the property.

## COMMERCIAL HARVEST PLOT

The commercial harvest plot is actually a demonstration of the conventional method of harvesting.

The plot shows the vast amount of material left in the forest after the logger has taken out choice trees and left broken stems, large limbs, tops, and other residue that were once considered waste but now represents a valuable resource when converted into chips or used for firewood.

It is material that could not be feasibly removed some years ago, but with the modern machinery of today - including the feller buncher, grapple skidder and chipper - it represents potential added income to the landowner and a valuable contribution to the campaign to ease the energy shortage.

*A Commission forester advises a landowner on the wisest and most profitable use of his timber. The bulk of Georgia's forests - some 23,267,500 acres - belongs to private landowners.*

| | Bd. Ft. | Cords | Tons |
|---|---|---|---|
| **Estimate** | | | |
| Pine Sawtimber | 2,885 | | 20.0 |
| Pine Pulpwood | | 1.5 | 4.0 |
| Hardwood Sawtimber | 0 | | 0 |
| Hardwood Pulpwood | | 10.0 | 28.0 |
| **Actual Volume Harvested** | | | |
| Pine Sawtimber | 2,881 | | 20.0 |
| Pine Pulpwood | | 1.5 | 4.0 |
| Hardwood Sawtimber | 0 | | 0 |
| | | | 24.0 |
| **Biomass Remaining on Plot** | | | |
| Hardwood Pulpwood (no market) | | 10.0 | 28.0 |
| Tops, Undersize stems, limbs | | | 5.0 |
| | | | 33.0 |
| Estimate of Total Biomass | | | 57.0 |

## CONTROL PLOT

Two one-acre plots in the demonstration area are left in their natural state in order that the observer can compare them with adjacent plots in which harvesting and other forest management practices have been carried out.

By leaving the stand intact, foresters are able to point out several alternatives that a landowner could take if similar property were to be managed.

| | Bd. Ft. | Cords | Tons |
|---|---|---|---|
| Estimate | | | |
| Pine Sawtimber | 1,100 | | 7.7 |
| Pine Pulpwood | | 3.7 | 9.8 |
| Hardwood Sawtimber | 455 | | 3.4 |
| Hardwood Pulpwood | | 3.5 | 10.2 |
| Total Merchantable Volume | | | 31.1 |
| Volume of tops, limbs, cull and undersized trees | | | 33.9 |
| Estimate of Total Biomass | | | 65.0 |

## CLEAR CUT

**The clearcut, or harvest cut plot, demonstrates total removal of the timber stand for the purpose of regenerating a more valuable acre of timber. Foresters graded the timber in the plot and it was sold for its highest value. After removal of the sawtimber, the undesirable trees, limbs and remaining biomass were chipped. The two fold objective of the demonstration is to show landowners how this method of harvest can save the cost of site preparation, which would run approximately $135 on the type area shown, and at the same time realize additional income from the sale of chips produced from biomass**

| | Bd. Ft. | Cords | Tons |
|---|---|---|---|
| Estimate | | | |
| Pine Sawtimber | 1,700 | | 12.0 |
| Hardwood Sawtimber | 70 | | .6 |
| Actual Volume Harvested | | | |
| Pine Sawtimber | 1,714 | | 12.0 |
| Hardwood Sawtimber | 75 | | .6 |

| | Tons |
|---|---|
| Estimate of Total Biomass | 93.0 |
| Actual Biomass Yield After Chipping | 96.0 |
| Estimated Site Preparation Cost - $0.00 | |
| Estimated Cost of Planting (Including Seedlings) -$44.00 | |

## SELECTIVE THINNING

The plot devoted to selective thinning-sometimes called environmental harvesting-consists of typical North Georgia hardwood. Forestry crews cut out the small stems, hollow trees, species with poor form and other undesirable growth in the understory. Desirable trees are left for future timber crops.

The object of the study is to show landowners how they can vastly improve their timber stand and at the same time realize revenue from low grade and cull materials that can be converted to chips.

| Estimate | Bd. Ft. | Cords | Tons |
|---|---|---|---|
| Pine Sawtimber | 2,442 | | 17.1 |
| Pine Pulpwood | | 0 | 0 |
| Hardwood Sawtimber | 1,324 | | 9.9 |
| Hardwood Pulpwood | | 6 | 17.4 |
| Biomass in tops, limbs, etc. | | | 20.9 |
| Actual Volume Harvested (cull, unmerchantable trees) | | | 48.2 |
| Estimate of Total Biomass | | | 113.5 |

## SELECTIVE THINNING CONTROL PLOT

| Estimate | Bd. Ft. | Cords | Tons |
|---|---|---|---|
| Pine Sawtimber | 1,000 | | 7.0 |
| Pine Pulpwood | | 2.0 | 5.3 |
| Hardwood Sawtimber | 1,200 | | 9.0 |
| Hardwood Pulpwood | | 5.0 | 14.5 |
| Cull Unmerchantable Trees | | | 61.2 |
| Estimate of Total Biomass | | | 97.0 |

## FIREWOOD PLOT

An acre consisting mostly of hardwood is set aside as a firewood plot to show the type of trees that can be profitably harvested for this purpose. It is also emphasized that by taking out poor quality trees for fuel purposes, the entire stand is vastly improved.

| Estimate | Bd. Ft. | Cords | Tons |
|---|---|---|---|
| Pine Sawtimber | 770 | | 5.4 |
| Pine Pulpwood | | .5 | 1.3 |
| Hardwood Sawtimber | 1,350 | | 10.1 |
| Hardwood Pulpwood | | 6.2 | 17.3 |
| Estimated Volume for Firewood | | 6.0 | 16.8 |
| Actual Volume Harvested - Firewood | | 6.7 | 18.8 |
| Biomass in Tops, Limbs, Slash | | | 25.5 |
| Estimate of Total Biomass* | | | 79.0 |

## FIREWOOD PLOT (MARKED)

| Estimate | Bd. Ft. | Cords | Tons |
|---|---|---|---|
| Pine Sawtimber | 2,420 | | 16.9 |
| Pine Pulpwood | | 2.9 | 7.7 |
| Hardwood Sawtimber | 1,575 | | 11.8 |
| Hardwood Pulpwood | | 7.0 | 20.3 |
| Total | 3,995 | 9.9 | 56.7 |
| Undersized Trees | | | 7.5 |
| Firewood Marked | | 7.0 | |
| Understory, Tops, Limbs, Etc. | | | 33.8 |
| Estimate of Total Biomass | | | 98.0 |

*Due to estimated and actual figures, the total biomass does not reflect the sum of the column.

*The demonstration clearcut plot is shown at the top, while the other photo provides a view of a plot harvested by the conventional commercial method.*

*The plot at right represents an improvement, or thinning cut. Poor quality trees taken from the plot were converted into chips, while high grade stock was released for better growth.*

*The control plot is left undisturbed so landowners and others can compare it with surrounding plots on which the various forestry harvest practices have been carried out.*

*The ribbon designates the trees in this firewood study plot to be left for higher quality products. The non-designated trees will be removed for firewood.*

These three machines have revolutionized the harvest of forests in recent years and have made it feasible and profitable to reclaim woodland materials that were formerly considered waste. The powerful feller buncher above is shown shearing a tree at ground level. The grapple skidder (top right) transports several trees at a time to the chipper shown at right. The chips are blown into a waiting van for travel directly to the Northwest Regional Hospital or to other locations where they will be used for other purposes.

# GASIFICATION

## A METHOD OF EXTRACTING ENERGY FROM THE FORESTS OF GEORGIA

The project to design, construct and install a wood gasification system had its beginning in [illegible] when the Forestry Commission, with the engineering assistance of the Technology Application Laboratory at Georgia Tech, began work on this important development that would greatly enhance the utilization of wood energy.

A statewide search was made for a demonstration site, and the Northwest Georgia Regional Hospital in Rome was chosen. Three companies entered bids for the construction and installation of a wood gasification system, and the contract was awarded to Applied Engineering Company of Orangeburg, South Carolina.

The gasification system has been completed and is now in operation. The economics of the system are being closely monitored to verify that the gasifier meets the performance criteria. Favorable results will bring about similar installations in other state facilities and in private industry.

The green total tree chips, approximately 2" x 2" mixed hardwoods and softwoods, are delivered to the hospital by chip vans with a capacity of 22-25 tons. The chip vans are unloaded by a Phelps Hydraulic Unloader into a live action hopper, which will hold one van load of chips. From the hopper, the wood chips are conveyed to a silo, which will hold 3½ days supply of wood (23,000 cu. ft.) for the gasifier. The chips move from the silo by a conveyor to the 25 million BTU/hr. updraft gasifier as illustrated in Figure 1.

The low BTU gas (150 BTU/ft.³) is piped 100 feet from the gasifier to the wood gas burner. The burner has been designed to replace the conventional natural gas and oil burner on the existing 500 hp boiler.

The total tree harvesting contractor will provide the wood chips and unload each van upon delivery and activate the automatic system that will carry the wood chips to the silo. The system is designed to allow the one boiler attendant on duty to operate the wood gasifier as the natural gas or oil boilers have been operated in the past. A detailed control panel inside the boiler room will keep the boiler attendant informed of data relating to the operation of the gasifier.

The gasifier will use about three tons per hour of total tree wood chips with a moisture content of approximately 45-50 percent. The system will provide enough energy to produce 19,000 pounds of steam per hour, which will meet most of the hospital's steam needs for much of the year. Certain peak demands will require part-time use of another boiler. The wood gasifier will be utilized year-round since an absorption unit is used to air condition the hospital during the summer.

The wood chips enter the gasifier through a rotary air lock. The vertical pressure vessel is about 20 feet high and 8 feet in diameter. Temperatures inside the unit reach 2,000°F., high enough to chemically convert the wood chips to the combustible low BTU gas. Some drying of the wood chips occur in the top of the vessel as the hot gases move through the chips before going to the burner as shown in Figure 2. Ash is automatically removed with an auger system.

This system is a fully operational, first generation system, which will provide real advantages over conventional fuels such as oil and natural gas. Applied Engineering Company indicates that the state should recover a payback on its investment in approximately two years.

A view of the gasifier at Rome is shown on the cover, while another is presented at left. Energy produced by the equipment will be used to both heat and air condition the hospital.

# WOOD GASIFICATION SYSTEM

## NORTHWEST REGIONAL HOSPITAL

## ROME, GEORGIA

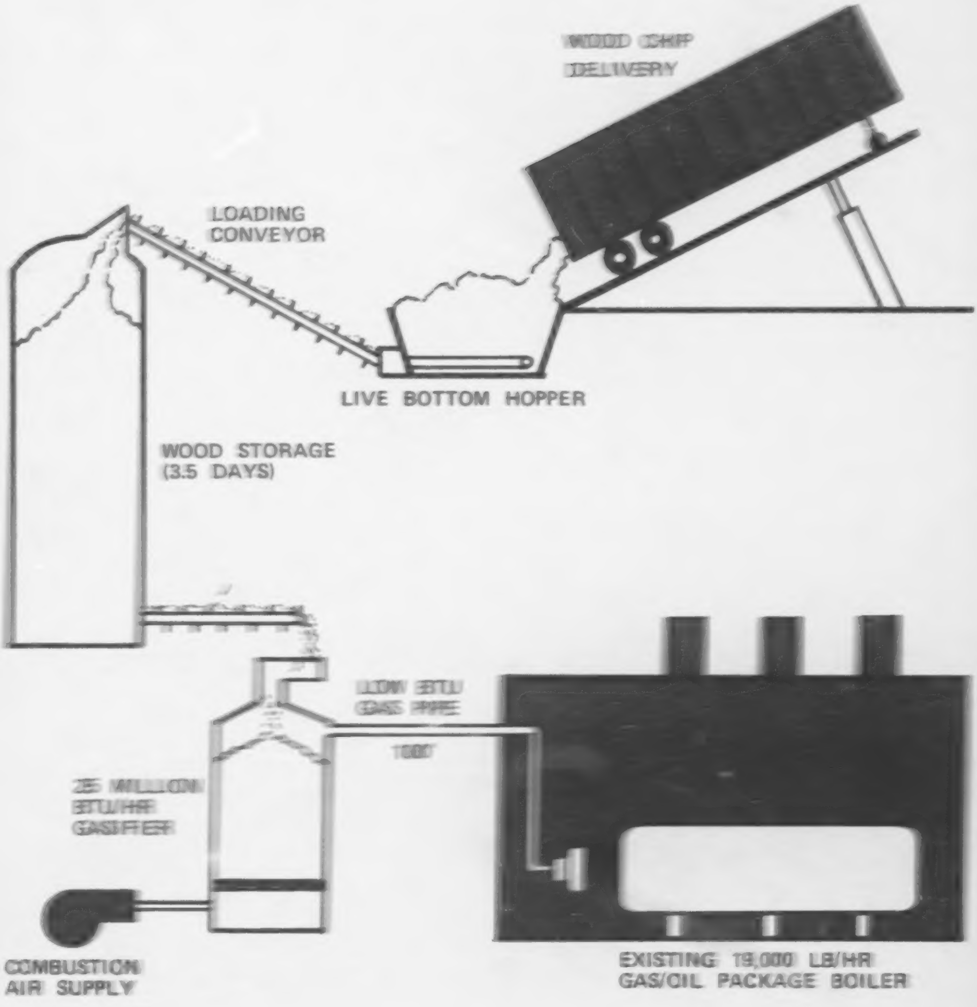


*Figure 1*

*At left, green wood chips are transported directly from the forests in conventional chip vans. Below, chip storage studies are being conducted by the Commission to determine BTU content, moisture content, deterioration and pile design.*

WOOD GASIFIER

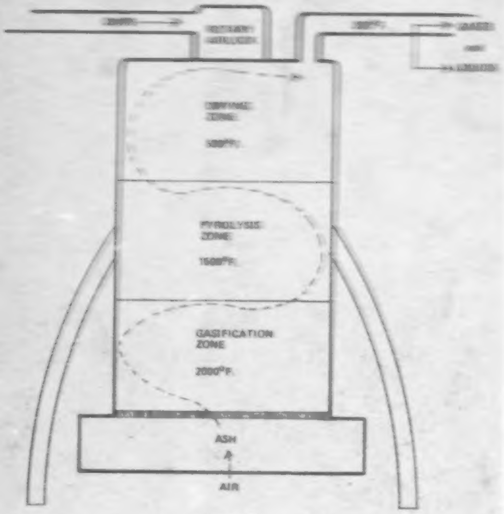


*figure 2*

# DRYING WITH WOOD

## WOOD CHIPS USED AS FUEL IN DRYING AGRICULTURAL CROPS

Georgia's farmers presently spend 20 million dollars per year on propane gas for crop drying. After studying several systems, with plans to develop a wood agricultural dryer, a unit originally designed for lumber drying was selected and modified to attach to a crop dryer. This wood chip furnace, developed by Rettew Associates, Inc., will burn green total tree wood chips and will generate up to 3 million BTU/hr.

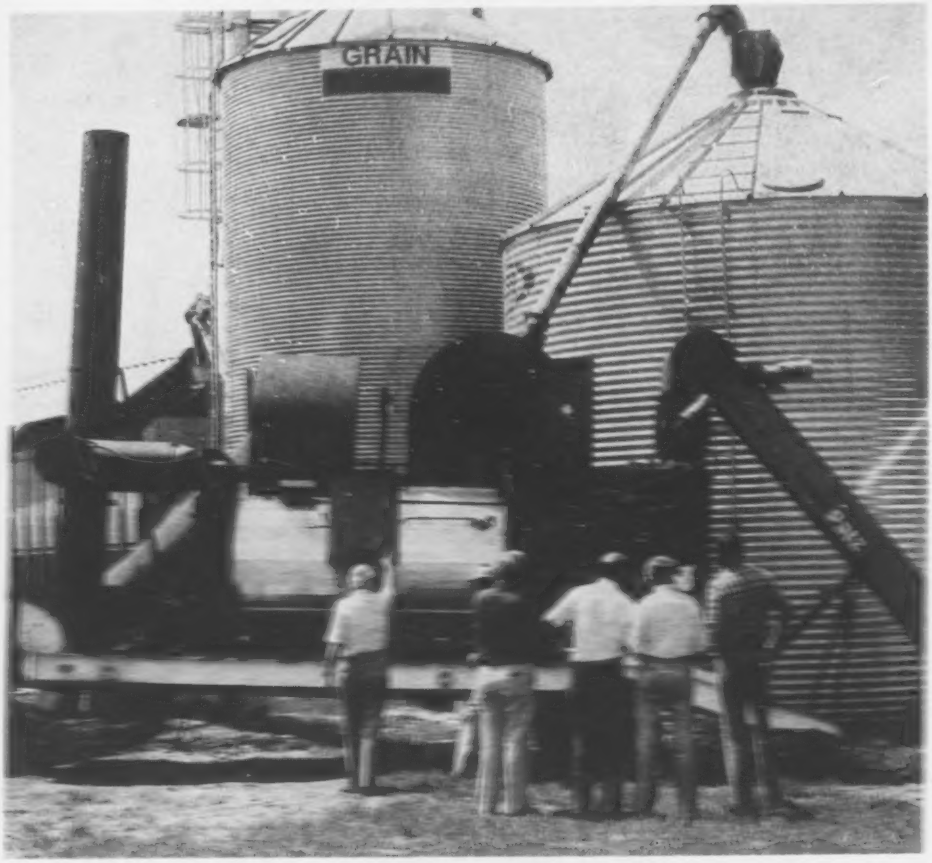
The wood chip furnace is mounted on a trailer to allow easy moves from one farm to another. A conventional John Deere forage trailer was tested and proved very successful as a storage vehicle for the wood chips. A Ratz heavy duty agricultural conveyor was added to the unit to enable the wood chips to be conveyed from the forage trailer to the wood furnace. The forage trailer and conveyor was synchronized with the electronic control panel of the furnace. Various safety devices are present on the furnace, enabling safe operation and shutdown if necessary.

The wood chips are conveyed from the forage trailer to a rotary air lock on the furnace. The chips pass through the rotary air lock and slide down a sloping wall to the pinhole grate, where the fuel is burned. Underfire air is blown through the pinhole grate to keep the wood chips burning. From the area above the grates, the hot gases pass over a six-inch firewall into a secondary combustion chamber and then into the firetubes of the heat exchanger.

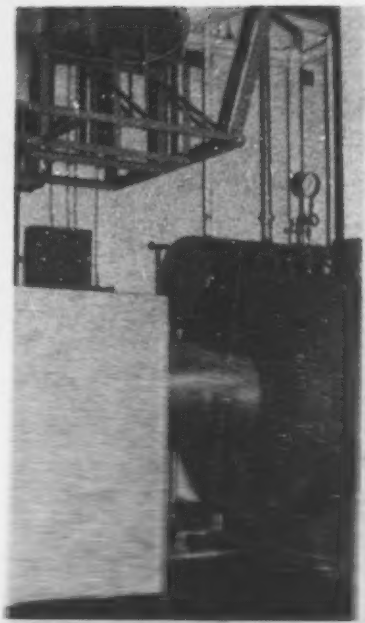
The agricultural crop dryer produces hot air up to 200°F. The hot air is moved from the furnace at 16,000 CFM. The wood chip furnace was tested as the heat source for a conventional agricultural dryer. Preliminary data indicated that the fuel cost can be reduced by one-half using wood chips instead of propane.

This system is being demonstrated throughout the state to show farmers that wood can be used to dry agricultural crops. Also, the Commission is studying the possibility of using the wood system to heat poultry houses and serve the agricultural and manufacturing interests of the state in other ways.

*The scene at left depicts how millions of BTU's are wasted each year as land is cleared and the biomass burned. The wood burning unit, shown above, was designed to dry lumber but is being adapted by the Commission to dry corn, soybeans and other grains.*



*Many farmers dry their grains on the farm today before storing. The wood burning furnace using green wood chips, shown above, is demonstrated on a farm in South Georgia. A conventional forage box, at left, is used to transport the green wood chips from the local sawmill to the farm where the wood chip dryer is located.*



# HEATING WITH WOOD

## WOOD SOURCE OF FUEL USED TO HEAT A GEORGIA PUBLIC SCHOOL

The Union County Junior High School in Blairsville, Georgia, is believed to be the only public school in the Southeast in modern times to be heated by wood chips.

A system installed by the Forestry Commission is now operational at the school and features the use of green wood chips from a local sawmill as fuel.

Unlike the pot-bellied wood stove that stood in the classroom corner in a bygone era, the system at Blairsville is a fully automated method engineered by Dr. John G. Riley, a professor at the University of Maine. The system had met the requirements at three installations during the harsh winters of that state before it was installed in the Georgia school.

The wood chips are transported to the school from the sawmill in a New Holland forage trailer, and then moved onto a live bottom hopper in the boiler room by means of a conveyor.

From the hopper, the chips travel by a screw conveyor to a firebox which was constructed on the boiler room floor. The Dutch oven-type firebox is direct fired and generates approximately 500,000 BTU/hr. The steam from the wood fire boiler heats a portion of the school building. Because of the extremely high combustion temperatures, the stack emissions are very low.

The system replaces a fuel oil burner, which has been retained to provide the school with a dual system in the event of an emergency.

One unique feature of the system is the routing of excess heat from the stack to the chip storage area to help dry the material.

The system will use approximately 700 pounds of chips per twenty-four hour day of operation and school officials have declared that the cost compared to the fuel formerly used shows a significant saving.

The project was a cooperative effort between the Georgia Forestry Commission, Tennessee Valley Authority, and the Union County School System.

*A wood burning unit at the junior high school, top left, is shown with an inside chip bin in the background. Bottom scene shows green wood chips which are available from many sawmills in the state. Schools may purchase wood chips from local mills or from total tree harvesters. The Dutch oven type firebox, above, is connected to a boiler that provides steam for heating a portion of the school.*

## RELATIVE ENERGY COSTS

## CALCULATIONS $/Million BTU

| FUEL | PRICE | ENERGY COST | AVERAGE COST ROME Oct. 1980 |
|---|---|---|---|
| WHOLE TREE WOOD CHIPS<br>8 million BTU/ton | PER TON<br>$10.00<br>15.00<br>20.00<br>25.00<br>30.00 | PER MIL. BTU<br>$ 1.25<br>1.87<br>2.50<br>3.12<br>3.75 | WHOLE TREE WOOD CHIPS<br>(Delivered to Rome)<br>Per Ton<br>$16.32 ($2.04)* |
| NATURAL GAS<br>1,000 BTU/cu.ft. | PER THERM<br>$ .25<br>.30<br>.40<br>.50<br>.60 | PER MIL. BTU<br>$ 2.50<br>3.00<br>4.00<br>5.00<br>6.00 | NATURAL GAS<br>Per Therm<br>$ .35 ($3.50)* |
| NO. 2 FUEL OIL<br>140,000 BTU/gal | PER GALLON<br>$ .60<br>.70<br>.80<br>.90<br>1.00 | PER MIL. BTU<br>$ 4.29<br>5.00<br>5.71<br>6.43<br>7.14 | NO. 2 FUEL OIL<br>Per Gal<br>$ .91 ($6.50)* |
| ELECTRICITY<br>(3,413 BTU/KWH) | PER KWH<br>$ .020<br>.035<br>.040<br>.045<br>.050 | PER MIL. BTU<br>$ 5.86<br>10.25<br>11.72<br>13.18<br>14.64 | ELECTRICITY<br>Per KWH<br>$ .045 ($13.18)* |
| PROPANE<br>92,000 BTU/gal | PER GALLON<br>$ .45<br>.50<br>.55<br>.60<br>.65 | PER MIL. BTU<br>$ 4.89<br>5.43<br>5.98<br>6.52<br>7.07 | PROPANE<br>Per Gal<br>$ .68 ($7.40)* |

*Per Million BTU

# ACKNOWLEDGEMENTS

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GEORGIA FOREST
RESEARCH PAPER

4
JUNE, 1979

# WHOLE TREE CHIPPING
## . . . A FOREST MANAGEMENT TOOL

BY
PAUL M. BUTTS AND DRUID N. PRESTON

RESEARCH DIVISION
GEORGIA FORESTRY COMMISSION

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# WHOLE TREE CHIPPING — A FOREST MANAGEMENT TOOL

BY

PAUL M. BUTTS AND DRUID N. PRESTON

## INTRODUCTION

Chipping of whole trees for fiber or fuel is a relatively recent innovation in timber harvesting. Since it has become a common practice, whole tree chipping by portable units is recognized as an efficient means of obtaining maximum wood yield as well as a way to promote forest management. Development of supporting equipment such as mechanical fellers, feller-bunchers, rubber-tired skidders, and other modern logging equipment has increased the efficiency of these chippers and has enabled them to gain the widespread use they have today.

The chipper is the major component of this specialized and mechanized timber harvesting system (Figure 1). Mechanical fellers, such as hydraulic shears, are usually used because of their speed and capability of severing trees at ground line. This leaves no stumps to interfere with movement of other equipment. If combination feller-bunchers are used, tree stems or boles can be placed in piles convenient for skidding (Figure 2). Rubber-tired grapple skidders (Figure 3), or cable skidders, are used to transport piles of stems to a chipping site.

At the chipping site, trees are deposited in a convenient location for the chipper operator to pick up with a boom-type loader attached to the chipper. Stems are then placed on the infeed conveyor where they are fed into the chipper by powered rolls. These rolls also compress the tops so that they can more readily enter the chipper throat or infeed opening.

Wood is diagonally cut into chips by knives attached to a spinning slotted disc. Chips pass through these slots as they are cut, and then through a discharge spout into a chip van.

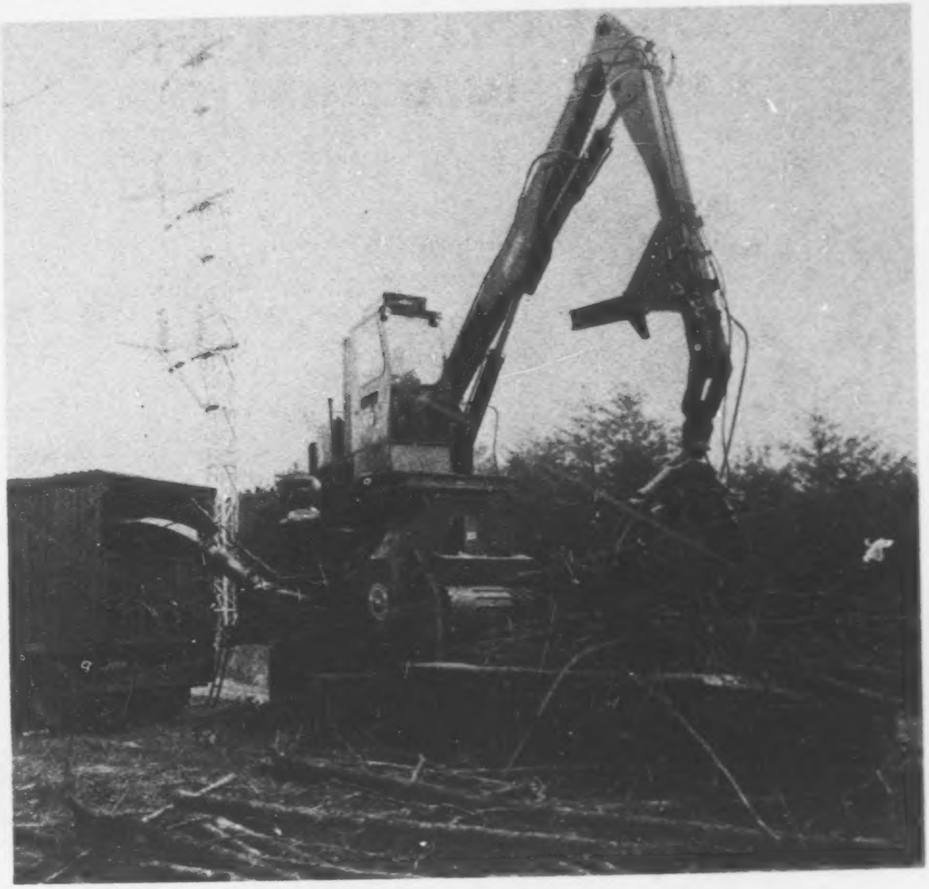

Figure 1.—Portable Whole Tree Chipper

## ADVANTAGES

Whole tree harvesting offers varied options to the forest manager and logger, which are not always available with conventional logging systems. Some of these advantages and benefits are:

I. Quantities of wood material recovered are significantly increased over conventional harvesting. All tops, limbs, cull and small trees, and non-commercial species can be converted into a useable product. The large volume of wood available from small trees in Georgia is shown in Table 1.

II. Whole tree chipping can be an effective forest management tool for removing otherwise unuseable cull and suppressed trees, leaving the better trees for growth and future harvest (Figures 4 & 5).

III. Many tracts do not return to full timber production after conventional harvesting because of the relatively large, long-term investment required for site preparation. Whole tree harvesting can reduce or eliminate site preparation costs. Also, clearing of logging debris and residual trees is minimal or unnecessary (Figure 6). By elimination of windrows and debris piles, more area is available for planting.

IV. Many acres of forest land are considered unproductive because the quality and species present are unsuitable for conventional products or markets. Whole tree chips provide a profitable use for this wood and allow the site to be converted to productive forest.

V. All tree species and qualities of wood can be used. This is particularly true if chips are to be used for energy. The presence of bark, which is unacceptable in some pulping operations, is of little importance in fuel chips.

VI. Fire hazard is greatly reduced due to the small amount of slash left on site after logging. This also means that if fires do occur, suppression will be much faster and more effective.

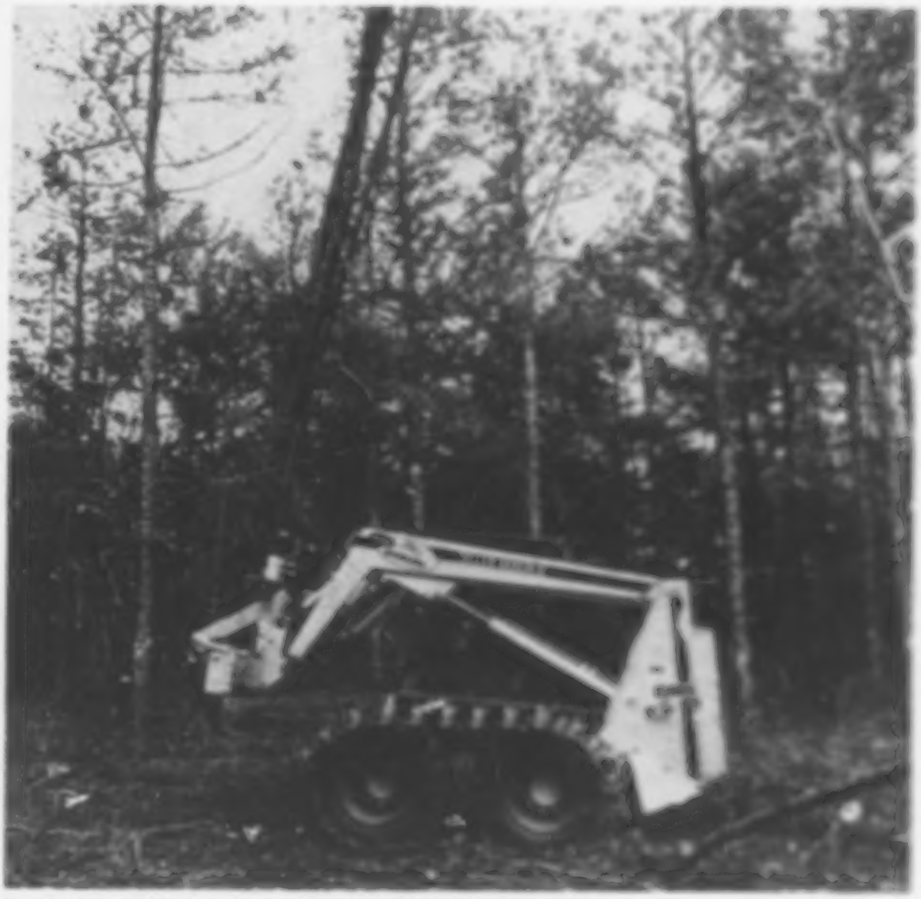

Figure 2.—Feller Buncher Equipped for Multiple Stem Accumulation

TABLE 1.--VOLUME OF SMALL TREES ON COMMERCIAL FOREST LAND IN GEORGIA[1]

| Species | ALL LIVE TREES[2] | | | | GROWING STOCK[3] | | | |
|---|---|---|---|---|---|---|---|---|
| | - - - - Diameter (Inches)[4] - - - - - | | | | - - - - Diameter (Inches)[4] - - - - - | | | |
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| | ------------Thousand Cubic Feet---------- | | | | ----------Thousand Cubic Feet---------- | | | |
| Pine | 122,863 | 389,415 | 746,917 | 1,059,308 | 103,881 | 351,427 | 703,807 | 1,005,585 |
| Other Softwoods | 14,908 | 23,494 | 32,092 | 39,140 | 12,970 | 21,635 | 29,049 | 33,678 |
| Total Softwoods | 137,771 | 412,909 | 779,009 | 1,098,448 | 116,851 | 373,062 | 732,856 | 1,039,263 |
| Soft Hardwoods | 279,948 | 405,197 | 514,011 | 611,357 | 124,204 | 235,505 | 324,508 | 440,214 |
| Hard Hardwoods | 284,334 | 446,245 | 530,060 | 585,952 | 71,001 | 162,860 | 245,504 | 296,574 |
| Total Hardwoods | 564,282 | 851,442 | 1,044,071 | 1,197,309 | 195,205 | 398,365 | 570,012 | 736,788 |
| Total All Species | 702,053 | 1,264,351 | 1,823,080 | 2,295,757 | 312,056 | 771,427 | 1,302,868 | 1,776,051 |

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[1] Southeastern Forest Experiment Station, USFS

[2] All Live Trees includes desirable and acceptable trees of commercial species, as well as rough and rotten trees, and trees of non-commercial species.

[3] Growing Stock includes desirable and acceptable trees of commercial species.

[4] Diameter class range is full inch through .9 inch, measured 4½ feet above ground.

VII. Whole tree harvesting also leaves more options open to the landowner and land manager. Conversion of unproductive timber land to agricultural or other uses may be desired. For example, recently harvested areas have been harrowed, seeded, and changed to pasture in only a few weeks.

VIII. Removal of small stems and culls are possible, thereby making revenues available which would normally be lost. Large remaining timber can then be logged more easily and less expensively.

IX. Portable chippers can be used in disaster situations and for other occasions. High winds, floods, and ice storms often leave large quantities of wood which must be quickly removed to clear roads, power lines, and eliminate the threat of insects and diseases. Also, this wood usually must be quickly salvaged before it deteriorates or becomes unuseable.

X. For the logger, whole tree chipping is an efficient woods-to-mill system that provides rapid flow of large quantities of wood. Production rates of 250 tons and more of chips per day are being realized. By means of this system, several loading, unloading, and other handling processes can be eliminated.

XI. Quick set-up of equipment facilitates movement from one chipping site to another. This allows greater flexibility in skidding and overall planning. The efficient harvest of relatively small tracts is also made practical.

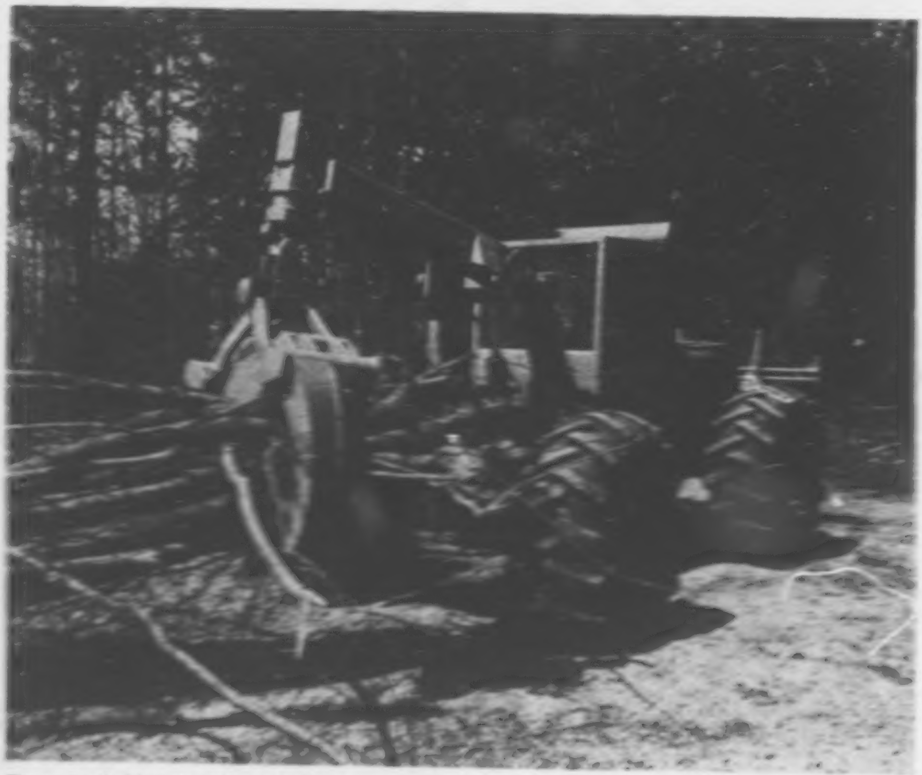

Figure 3.—Rubber-Tired Grapple Skidder

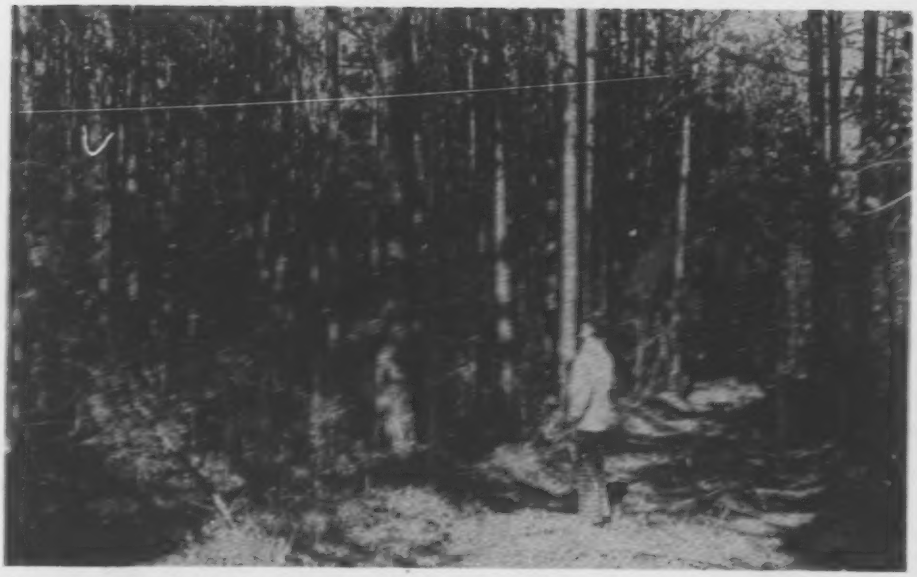

Figure 4.—Timber Stand with Large Volume of Small, Unmerchantable Wood

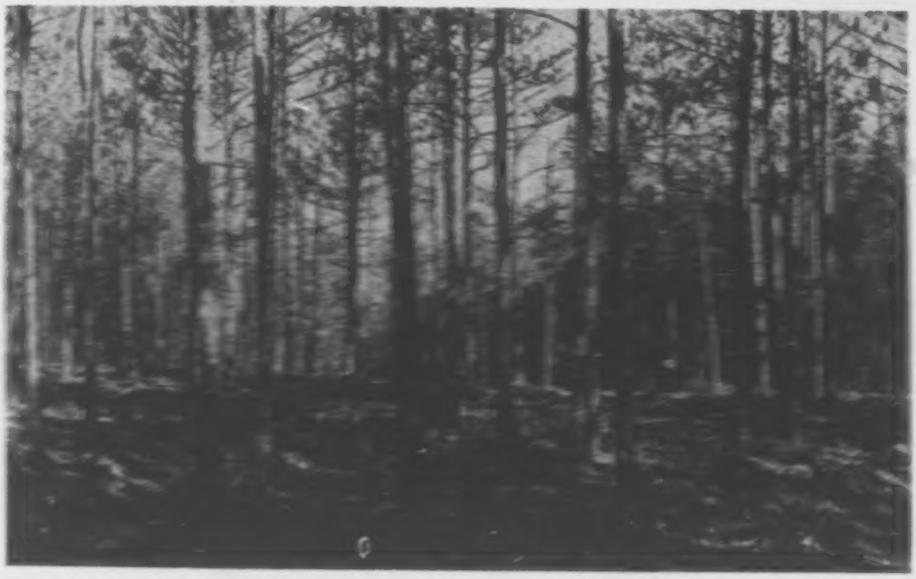

Figure 5.—Same Timber Stand Shown in Figure 4, After Removal of 28 Tons of Wood Material Per Acre by Whole Tree Chipping

TABLE 2.--AN EXAMPLE OF EQUIPMENT USED IN A WHOLE TREE CHIPPING OPERATION

| No. | Equipment | No. | Equipment |
|---|---|---|---|
| 1 | Portable Chipper | 1 | Log Truck |
| 2 | Grapple Skidders | 2 | 2-Ton Trucks |
| 1 | Cable Skidder | 1 | Crawler Tractor |
| 1 | Feller-Buncher | 2 | Pickup Trucks |
| 3 | Truck Tractors | 1 | Log Loader |
| 3 | Chip Vans | | |

# DISADVANTAGES

As with any industrial method, the use of portable whole-tree chippers has some limitations and disadvantages.

I. These machines cannot be used efficiently without a balanced support system of fellers, skidders, chip vans, etc. Due to the high cost of the chipper and accessory equipment, the system must operate daily at near capacity. Investment for a single chipper operation may require [illegible] or [illegible] (Table 2).

II. High standards of management, supervision, equipment coordination, and maintenance are required. Skill and motivation of equipment operators is often as significant as machine capability.

III. Presence of non-uniform chips, leaves and grit cause some pulp mills to limit the percentage of whole tree chips used. This, along with high capital investment, may limit the use of portable in-woods chipping systems.

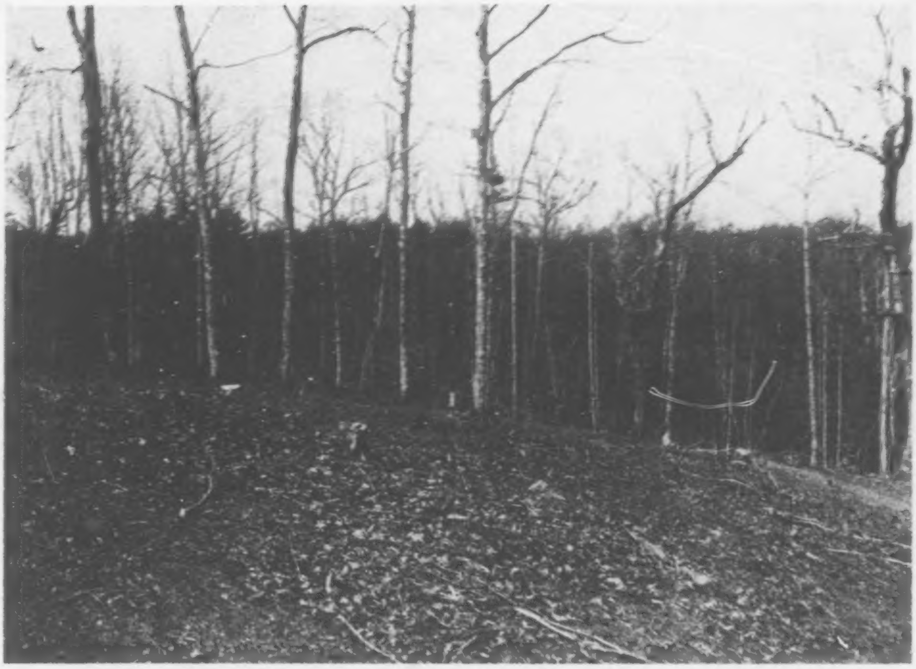

Figure 6.—A Clearcut Site, After Harvesting with Whole Tree Chipping, Showing Suitability of the Area for Replanting

## SUMMARY

Whole tree chippers have proved their capability and value in all forested areas of our nation. They can handle any species and convert any practical size of trees into chips for pulp, fuel, or other uses. The use of these chipping systems has increased greatly over the past ten years, and twenty-seven are now reported to be operating in Georgia.

Volumes of wood obtained from any given tract of timber can be increased one and a half to two times over volumes obtained from conventional logging systems. This increased saleable wood volume, along with reduced site preparation, timber stand improvement, and other advantages, makes the use of whole tree chippers practical and reasonable for harvesting many stands of timber.

GEORGIA FOREST
RESEARCH PAPER

7
AUGUST, 1979

# A TEST OF PREDICTION EQUATIONS FOR ESTIMATING HARDWOOD UNDERSTORY AND TOTAL STAND BIOMASS

BY

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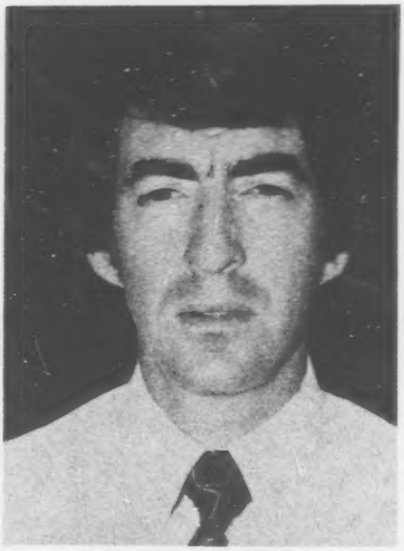

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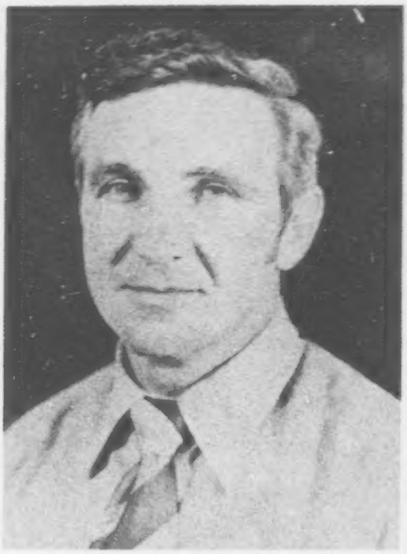

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# A TEST OF PREDICTION EQUATIONS FOR ESTIMATING HARDWOOD UNDERSTORY AND TOTAL STAND BIOMASS

By
Douglas R. Phillips, Mensurationist
and
Joseph R. Saucier, Principal Wood Specialist

## INTRODUCTION

Recently, foresters have begun to look at entire stands, including tops, understory trees, and cull trees as sources of fiber for fuel. Chipping of these formerly unused trees and tree parts yields large amounts of fiber, and foresters must be able to estimate the quantities involved. In response to this need for information, forest products researchers have developed equations for predicting green weight (biomass) of total trees and portions thereof (1-10). Because the need was urgent, most of these equations were not field tested before publication. In this report are the results of a field test of equations for predicting weights of understory and overstory hardwoods. Most of the equations tested were developed in our Utilization of Southern Timber Project in Athens, Georgia. The results of the tests, conducted in a hardwood stand in northern Georgia, are quite encouraging.

## PROCEDURES

Ten 1/20-acre plots were established on a 3.19 acre tract of hardwoods in Dawson County, Georgia. The stand had an average basal area of 60.3 square feet per acre. All live trees 1.0 inches dbh and larger on each plot (radius = 26.3 feet) were tallied by species, dbh, and crown class. Each tree was felled, measured for total length, and weighed to the nearest pound. Understory trees 4.9 inches dbh and smaller were cut and weighed on the plot. Pulpwood trees and the tops of sawtimber trees from a 9-inch stem dob (diameter outside bark) to the tip, plus branches, were field chipped in a commercial total tree chipharvester. All chips from a plot were weighed in a truck with portable scales that were checked against commercial scales at a local pulpwood yard. Individual stem sections of sawtimber trees from the butt to a 9-inch dob top were weighed to the nearest pound on electronically operated platform scales. Separate totals were determined for understory and overstory trees on each plot.

# REGRESSION EQUATIONS USED

Regression equations available in the literature and some unpublished equations from our project were used to predict individual total tree weights. These equations are listed in Table 1. Some of the equations were used for two or three species even though they were developed for a single species. This was necessary since equations for all species are not available. The equations used had coefficients of determination ($R^2$) of 0.95 to 0.99 (Table 1), which indicates the equations fit the data on which they were based very well. Other information about the equations can be obtained from the original references.

# UNDERSTORY TREE WEIGHT PREDICTIONS

## Plot Means

Predicted green weight of understory trees on the 10 sample plots totaled 19,837 pounds or 720 pounds more than the actual weight of 19,117 pounds (Table 2). On individual plots, predicted total tree weight ranged from 1,096 to 3,343 pounds and averaged 1,984 pounds. On all but three plots the equations overestimated actual plot weights. Deviations of predictions from actual weights for plots ranged from -1.8 to +11.7 percent and averaged +3.8 percent. The largest error (+11.7 percent) occurred on plot 4, which contained 36 percent dogwood. The equation used to predict the weight of dogwood consistently overestimated tree weight.

## Species Means

Understory equations overestimated the weights of chestnut oak, dogwood, red oak, and other species, but underestimated the weight of yellow-poplar, hickory, white oak, and sourwood (Table 3). The largest underestimate was for yellow-poplar (-9.7 percent), and the largest overestimate was for dogwood (+17.2 percent). We do not know why the overestimate for dogwood was so large. We do know that the size and shape of the crown on this extremely shade tolerant species varies considerably with the amount of light it receives.

Most of the 486 understory trees were dogwood, red oak, hickory, or sourwood. Average tree dbh was 2.2 inches and average height was 25 feet.

# OVERSTORY TREE WEIGHT PREDICTIONS

Predicted total tree weight for the overstory trees on the 10 sample plots was 60,218 pounds, or 1,894 pounds below the actual weight of 62,112 pounds (Table 4). Deviations of predictions from actual weights on plots ranged from -22.0 to + 14.5 percent and averaged -3.0 percent (Table 4). Overstory trees were not weighed individually, so it was not possible to determine how accurately the equations predicted total tree weight by species.

Average dbh for the overstory trees was 8.9 inches, and average total height was 55.9 feet. Average dbh by plot ranged from 7.0 to 12.4 inches (Table 4). Most of the 62 overstory trees on the 10 plots were chestnut oaks, red oaks, yellow-poplar, and hickory.

Table 1. — Total tree green weight prediction equations used to estimate individual tree and total stand biomass.

| SPECIES | EQUATION[1] | $R^2$ | REFERENCE NO. |
|---|---|---|---|
| | **UNDERSTORY SPECIES** | | |
| Yellow-poplar | $\log_{10} Y = -0.61138 + 0.93557 \log_{10} (D^2Th)$ | 0.99 | 7 |
| Sweetgum<br>Loblolly pine<br>Shortleaf pine | $\log_{10} Y = -0.43892 + 0.87880 \log_{10} (D^2Th)$ | .97 | 7 |
| White oak | $\log_{10} Y = -0.33307 + 0.86574 \log_{10} (D^2Th)$ | .99 | 7 |
| Chestnut oak | $\log_{10} Y = -0.25205 + 0.83728 \log_{10} (D^2Th)$ | .98 | 7 |
| Post oak | $Y = 4.70542 + 0.18111 (D^2Th)$ | .99 | 8 |
| N. red oak<br>Black oak<br>S. red oak | $\log_{10} Y = -0.09254 + 0.77793 \log_{10} (D^2Th)$ | .95 | 7 |
| Dogwood | $\log_{10} Y = -0.15203 + 0.83686 \log_{10} (D^2Th)$ | .98 | 7 |
| Hickory | $\log_{10} Y = -0.45800 + 0.90556 \log_{10} (D^2Th)$ | .99 | 7 |
| Sourwood<br>Persimmon<br>Sassafras | $Y = 10.30660 + 0.17780 (D^2Th)$ | .99 | 8 |
| Black cherry | $\log_{10} Y = -0.36125 + 0.88931 \log_{10} (D^2Th)$ | .99 | 8 |
| | **OVERSTORY SPECIES** | | |
| Yellow-poplar | $\log_{10} Y = -0.69614 + 0.96067 \log_{10} (D^2Th)$ | 0.99 | 2 |
| Blackgum<br>Sweetgum | $Y = 0.03342 (D^2)^{1.03144} (Th)^{1.31046}$ | .98 | 1 |
| Loblolly pine | $\log_{10} Y = -0.78974 + 1.00404 \log_{10} (D^2Th)$ | .99 | 9 |
| Shortleaf pine | $\log_{10} Y = -1.20938 + 1.11931 \log_{10} (D^2Th)$ | .99 | 4 |
| White oak<br>Post oak | $Y = 0.14925 (D^2Th)^{1.03696}$ | .99 | 3 |
| Chestnut oak | $Y = 0.11649 (D^2Th)^{1.04876}$ | .98 | 3 |
| N. red oak<br>Black oak | $Y = 0.18579 (D^2Th)^{1.00655}$ | .99 | 6 |
| S. red oak<br>Scarlet oak | $Y = 0.06632 (D^2Th)^{1.11245}$ | .98 | 5 |
| Hickory | $Y = 0.15625 (D^2Th)^{1.01813}$ | .99 | 10 |
| Black cherry | $Y = 0.27025 (D^2Th)^{0.94754}$ | .99 | 10 |

[1] Y = total tree green weight, D = Dbh, Th = total height

Table 2.—Actual and predicted total tree green weights of understory hardwoods by plot number.

| Plot Number | Sample Trees | Average DBH | Average Total Height | Total Weight of Understory Trees Actual | Total Weight of Understory Trees Predicted | Difference |
|---|---|---|---|---|---|---|
| | Number | Inches | Feet | - - - Pounds - - - | | Percent |
| 1 | 32 | 2.7 | 28 | 1,876 | 1,869 | - 0.4 |
| 2 | 46 | 2.2 | 25 | 1,994 | 2,046 | + 2.6 |
| 3 | 66 | 2.4 | 27 | 3,084 | 3,343 | + 8.4 |
| 4 | 52 | 2.1 | 23 | 1,554 | 1,736 | + 11.7 |
| 5 | 42 | 2.2 | 23 | 1,608 | 1,738 | + 8.1 |
| 6 | 67 | 2.1 | 25 | 2,748 | 2,788 | + 1.4 |
| 7 | 33 | 2.1 | 22 | 1,132 | 1,155 | + 2.0 |
| 8 | 30 | 2.0 | 22 | 1,116 | 1,096 | - 1.8 |
| 9 | 55 | 2.0 | 24 | 1,856 | 1,844 | - 0.6 |
| 10 | 62 | 2.1 | 21 | 2,148 | 2,222 | + 3.4 |
| Average or total | 486 | 2.2 | 25 | 19,117 | 19,837 | + 3.8 |

Table 3.—Actual and predicted total tree green weights of understory hardwoods by species.

| Species | Sample Trees | Average DBH | Average Total Height | Total Weight of Understory Trees Actual | Total Weight of Understory Trees Predicted | Difference |
|---|---|---|---|---|---|---|
| | Number | Inches | Feet | - - - Pounds - - - | | Percent |
| Yellow-poplar | 38 | 2.8 | 33 | 2,664 | 2,406 | - 9.7 |
| Chestnut oak | 19 | 2.9 | 32 | 1,323 | 1,449 | + 9.5 |
| Dogwood | 186 | 2.0 | 21 | 5,099 | 5,974 | + 17.2 |
| Hickory | 63 | 1.7 | 22 | 1,575 | 1,488 | - 5.5 |
| Sourwood | 61 | 3.4 | 27 | 3,015 | 2,957 | - 1.9 |
| Red oaks | 85 | 2.5 | 31 | 4,106 | 4,134 | + 0.7 |
| White oaks | 11 | 2.4 | 26 | 475 | 474 | - 0.2 |
| Other species | 22 | 2.4 | 24 | 862 | 955 | + 10.8 |
| Average or total | 486 | 2.2 | 25 | 19,117 | 19,837 | + 3.8 |

Table 4.—Actual and predicted total tree green weight of overstory hardwoods by plot number.

| Plot Number | Sample Trees | Average DBH | Average Total Height | Total Weight of Overstory Trees Actual | Total Weight of Overstory Trees Predicted | Difference |
|---|---|---|---|---|---|---|
| | Number | Inches | Feet | - - - Pounds - - - | | Percent |
| 1 | 4 | 12.4 | 56.9 | 7,752 | 6,453 | - 16.8 |
| 2 | 5 | 11.8 | 42.5 | 8,823 | 9,057 | + 2.6 |
| 3 | 8 | 8.5 | 52.2 | 3,877 | 4,439 | + 14.5 |
| 4 | 8 | 7.6 | 54.6 | 6,639 | 6,569 | - 1.0 |
| 5 | 4 | 12.0 | 57.9 | 7,939 | 6,194 | - 22.0 |
| 6 | 11 | 6.4 | 50.1 | 3,688 | 3,548 | - 3.8 |
| 7 | 4 | 11.4 | 63.4 | 7,591 | 8,071 | + 6.3 |
| 8 | 5 | 9.7 | 57.6 | 5,810 | 6,188 | + 6.5 |
| 9 | 7 | 8.7 | 50.8 | 6,218 | 6,318 | + 1.6 |
| 10 | 6 | 7.0 | 43.2 | 3,775 | 3,382 | - 10.4 |
| Average or total | 62 | 8.9 | 55.9 | 62,112 | 60,218 | - 3.0 |

# SUMMARY AND CONCLUSIONS

The actual total tree green weight of all trees (understory and overstory) on the ten 1/20-acre plots was 81,229 pounds; 24 percent or 19,117 pounds was in understory trees, and 76 percent or 62,112 pounds was in overstory trees. Using equations available in the literature plus some unpublished equations, we predicted a total weight on all plots of 80,155 pounds or 1.7 percent below the actual weight. Understory tree weights were overestimated by 3.8 percent and overstory tree weights were underestimated by 3.0 percent. These prediction errors are quite low and very acceptable for most practical applications. It appears from these results that in broad applications the equations work extremely well.

On individual plots, prediction error ran as high as 11.7 percent for understory trees and 22.0 percent for overstory trees. Since some deviations were positive and some negative, most of the error was cancelled out and indications are that with adequate sampling, these equations will provide accurate predictions. Even so, the best approach in applying any set of regression equations is to test them on a small sample of trees before they are applied.

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GEORGIA FOREST RESEARCH PAPER

8

JANUARY, 1980

# WOOD AS A HOUSEHOLD ENERGY SOURCE IN GEORGIA

BY

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# WOOD AS A HOUSEHOLD ENERGY SOURCE IN GEORGIA

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Georgians are discovering the value of wood as a source of energy in the home. Confronted with the rising cost of natural gas, fuel oil, and electricity, a large and growing number of Georgia households are turning to the state's plentiful and renewable supply of wood as a means of minimizing home heating costs. This increasing use of wood for home heating can significantly reduce Georgia's dependence on scarce and costly fossil fuels.

The harvesting of hardwoods for firewood will provide Georgia timberland owners with an opportunity for earning a cash return on otherwise unmerchantable timber. Further, it will facilitate the management of Georgia's pine forest resource by reducing the cost of forest practices needed to increase the supply of pine to Georgia's important forest products industries.

In order to determine the current importance of wood as a source of home energy, a survey of over 2000 Georgia households was undertaken in the summer of 1979 by the Georgia Forestry Commission and the Contract Research Division of the College of Business Administration at Georgia State University. This survey is a statistically valid sample enabling reliable estimates of the use of firewood for home heating, cooking and water heating by Georgia households.

## SURVEY FINDINGS

### HOME FIREWOOD USE IS WIDESPREAD

In Georgia a total of 375,000 homes, one in four, use wood as a source of energy. Nearly all of these homes used wood for home heating. Less than five percent or 20,000 homes used wood for cooking, water heating, and other household purposes.

### WOOD IS PRIMARILY A SUPPLEMENTAL HOME FUEL

Most homes use wood as a supplemental fuel for home heating. Among all households surveyed, including those who did not use wood, more than two-thirds, or one million homes, used gas as the major fuel for home heating. Electricity ranked second as a source of space heating, accounting for nearly one-fourth or 350,000 households. But five percent of all Georgia households, or 74,000 homes, reported using wood as the primary source of space heating. This is twice the number of households reporting oil as the major space heating fuel.

| Major Source of Fuel for Home Heating | Households | |
|---|---|---|
| | Proportion | Number |
| All Fuels | 100.00% | 1,462,368 |
| Gas | 68.5 | 1,001,722 |
| Electricity | 23.9 | 349,798 |
| Wood | 5.1 | 73,996 |
| Oil | 2.2 | 32,611 |
| Other | .3 | 4,241 |

The supplemental characteristic of wood as a fuel source is indicated by the response from nearly two-thirds of the wood-using households that wood accounts for 25 percent or less of space heating requirements. There were, however, 141,000 homes that obtained more than 25 percent of heat requirements from wood, and nearly 45,000 homes depended on wood for over 75 percent of space heating needs.

| Proportion of Home Heating from Wood | Households | |
|---|---|---|
| | Proportion | Number |
| Wood-Using Homes | 100.0% | 375,204 |
| 25 percent or less | 62.4 | 234,240 |
| 26 to 50 percent | 18.9 | 71,101 |
| 51 to 75 percent | 6.7 | 24,989 |
| 76 to 100 percent | 12.0 | 44,874 |

The type of wood-burning equipment used relates importantly to the manner in which wood is used in the home. A limited number of homes utilize more than one type of wood-burning equipment; the 375,204 homes in Georgia using wood for heating contained 392,051 pieces of equipment. Among wood-using homes the most widely used type of equipment is the fireplace, with 85 percent of the homes reporting its use. This was followed in order by circulating heaters, airtight stoves and Franklin stoves as shown below:

| Type of Wood-Burning Equipment | Households | |
|---|---|---|
| | Proportion | Number |
| Fireplace | 85.1% | 319,149 |
| Circulating heater | 7.6 | 28,440 |
| Airtight stoves | 6.7 | 25,214 |
| Franklin stoves | 3.4 | 12,832 |
| Central wood furnace | .4 | 1,613 |
| Other | 1.3 | 4,803 |

The main reason respondents gave for using wood to heat homes is related to the role of wood as a supplemental energy source. A total of 196,000 homes, representing 52 percent of wood-burning households, reported that wood was used to reduce fuel costs. The next largest group, 120,000 homes, reported the enjoyment of the atmosphere of a fire as the main reason for using firewood. A summary of the main reason households burn firewood is tabulated below:

| Main Reason for Using Firewood | Households | |
|---|---|---|
| | Proportion | Number |
| Wood-Using Homes | 100.0% | 375,204 |
| Cut fuel costs | 52.3 | 196,419 |
| Enjoyable atmosphere | 32.0 | 120,028 |
| Supplemental heat | 12.8 | 48,026 |
| Heat or convenience | 2.9 | 10,731 |

## HOUSEHOLD WOOD USE IS INCREASING

Significantly, the widespread use of wood as a supplemental or major household fuel is a recent development. Although some households have been using wood for 20 years or longer, the average period of wood use is seven and one-half years. Indeed, half of the wood-using households reported they have been using wood for three years or less. This recent transition to wood by half of the current users importantly reflects the rising cost of energy since the 1973 oil embargo. An equally significant finding is that 208,000 of all Georgia households report plans to install new wood-burning equipment. If all households planning to install new wood-burning equipment actually do so, current wood consumption would increase by 55 percent. Facilitating this potential growth in the number of wood-using households and the volume of household wood use is the finding that 95 percent of existing wood users report satisfactory service from wood-burning equipment.

## ANNUAL CONSUMPTION AND VALUE OF WOOD USED FOR HOME HEATING

The 375,000 households that use wood for home heating reported the use of 800,000 cords annually. This level of firewood use represents an average of just over two cords per year per using family.

Households obtain firewood from numerous sources, with the majority or 200,000 families cutting wood from their own land. Among respondents, some of whom acquire firewood from more than one source, 24 percent cut wood from land owned by others while 32 percent purchase wood from dealers. The importance of firewood sources is summarized below:

| Source of Firewood | Households | |
|---|---|---|
| | Proportion | Number |
| Cut from own source | 53.3% | 199,984 |
| Cut from friend's source | 21.2 | 79,543 |
| Cut from state land | .5 | 1,876 |
| Cut from federal land | 2.3 | 8,630 |
| Buy from dealer | 31.7 | 118,940 |
| Other | 2.0 | 7,504 |

The economic consequence of firewood consumption is significant. The households that purchased wood reported using 237,000 cords in 1978. The outlay cost for this quantity of purchased firewood was $11,250,000, representing an average price of $47.38 per cord. It should be noted that the average price of $47.38 represents wood purchased as cut, split, delivered, and ready for burning at a higher price, and also wood purchased on the stump at a lower price because the buyer did the cutting and splitting.

If households install wood-burning equipment as planned, the estimated demand for firewood will rise by an additional 445,000 cords per year. Of this increased quantity, nearly 132,000 cords would be purchased at a cost of $6,250,000 assuming no change in the 1978 average price. Wood consumption per year for home heating would then total nearly 1,250,000 cords, of which 370,000 cords would be purchased at a cost of $17,500,000. The supplying of firewood is an embryonic growth industry in Georgia.

# IMPLICATIONS

## WOOD VERSUS FOSSIL FUELS AS AN ENERGY SOURCE

With the current emphasis on efficient alternative fuel sources, the increasing use of firewood in Georgia can contribute significantly to energy conservation and help reduce our dependency on imported oil and gas and also on the use of electricity for home heating. Firewood is not only a less expensive source of heat, it is also in plentiful supply in Georgia.

The heat value of wood is highly dependent on the species and grade of firewood and the type of wood-burning equipment used. In one study of air pollution in the pulp and paper industry, sponsored by the U. S. Environmental Protection Agency, oil and wood fuel sources were given the following heat values when burned in power boilers:

| | | |
|---|---|---|
| Oil | Btu's per gallon | 149,000 |
| Wood | Btu's per pound | 4,600 |

Firewood which has dried to 40 percent moisture content is estimated to weigh

*This North Georgia resident made a detailed study of wood burning stoves before purchasing heaters for his home and store. He said he is well pleased with efficiency of the airtight stoves and has realized a very substantial savings in fuel costs since converting from electricity and oil to wood.*

4,500 pounds per cord. Each cord of wood, then, has the heating equivalency of 139 gallons or 3.3 barrels of oil.

At these comparative heating values, the annual consumption of 800,000 cords of wood is equivalent to 2,640,000 barrels of oil. At a conservative cost of $22 per barrel this use of wood is equivalent to oil imports of $58,000,000. If wood consumption reaches 1,250,000 cords as planned with new equipment, the oil equivalency of its heating value would be 4,125,000 barrels with a value of $90,000,000 at today's oil prices.

Data on the heating values of natural gas were obtained from the Atlanta Gas Light Company. Based on 1,025,000 Btu's per 1,000 cubic feet of natural gas, the current consumption of 800,000 cords of firewood represents the heat obtainable from more than 16 billion cubic feet of natural gas. The projected consumption of 1,250,000 cords of wood would be the equal of over 25 billion cubic feet of natural gas at a cost of $72 million.

Electricity has a heating value of 3,413 Btu's per Kw, according to the Georgia Power Company. The comparative heating value, then, of one cord of wood is 6,065 Kw of electricity. The current annual consumption of 800,000 cords of firewood in Georgia is equal in heating value to five billion Kw. At a projected level of firewood use of 1,250,000 cords annually, the equivalent generation of heat would require 7.5 billion Kw of electricity.

Based on the foregoing analysis, the relative costs of 1,000,000 Btu's of heat energy generated by various fuel sources can be summarized as follows:

| Fuel | Cost per Unit | Cost per 1,000,000 Btu's |
|---|---|---|
| Wood | $47.38 per cord | $2.29 |
| Oil | $22.00 per barrel | $3.52 |
| Natural gas | $2.87 per 100 cu. ft. | $2.80 |
| Electricity | $.045 per kwh | $13.20 |

These varying energy sources involve the use of many types of heating equipment. The heating values used in this analysis represent the number of Btu's of heat energy than can be extracted per standard unit of fuel. The type of heating equipment used significantly determines the efficiency with which these varying sources of fuel energy are converted into usable heat in the home.

It can be anticipated that the use of wood as a supplemental fuel, currently and in the future, will have its greatest impact in altering the use first of natural gas and secondly of electricity in home heating. As noted earlier, 68 percent of homes in Georgia use gas as the major source of fuel while 24 percent use electricity. The actual savings on fuel oil imports can be expected to be minimal as only about two percent of homes use oil as a major fuel.

## IMPACT ON FORESTRY INDUSTRY

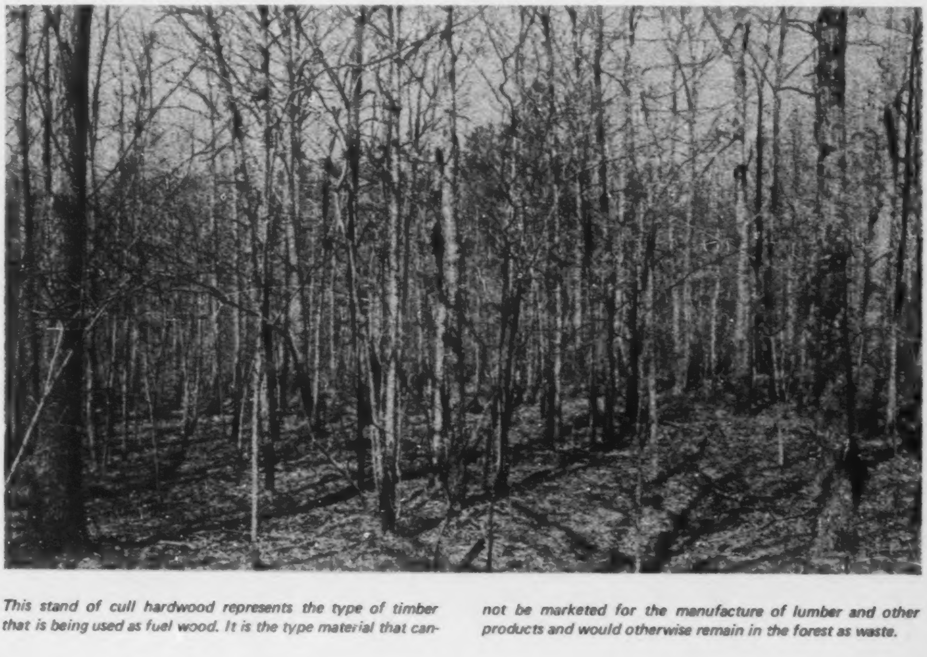
The current consumption of 800,000 cords of wood for home heating and the expected increase to 1,250,000 cords per year has had and will continue to have a significant influence on the forests in Georgia. One measure of the magnitude of wood used for heating homes is to compare it to the amount of wood used by the pulp and paper industry, a leading industry in Georgia. The current consumption of wood for home heating is equivalent to ten percent of the wood volume used in the pulp and paper industry.

It should be pointed out that the hardwoods utilized for home heating are not generally favored as forest products. Thus, the expanding demand for hardwoods as firewood will provide Georgia timberland owners with an opportunity to earn a cash return from otherwise unmerchantable timber.

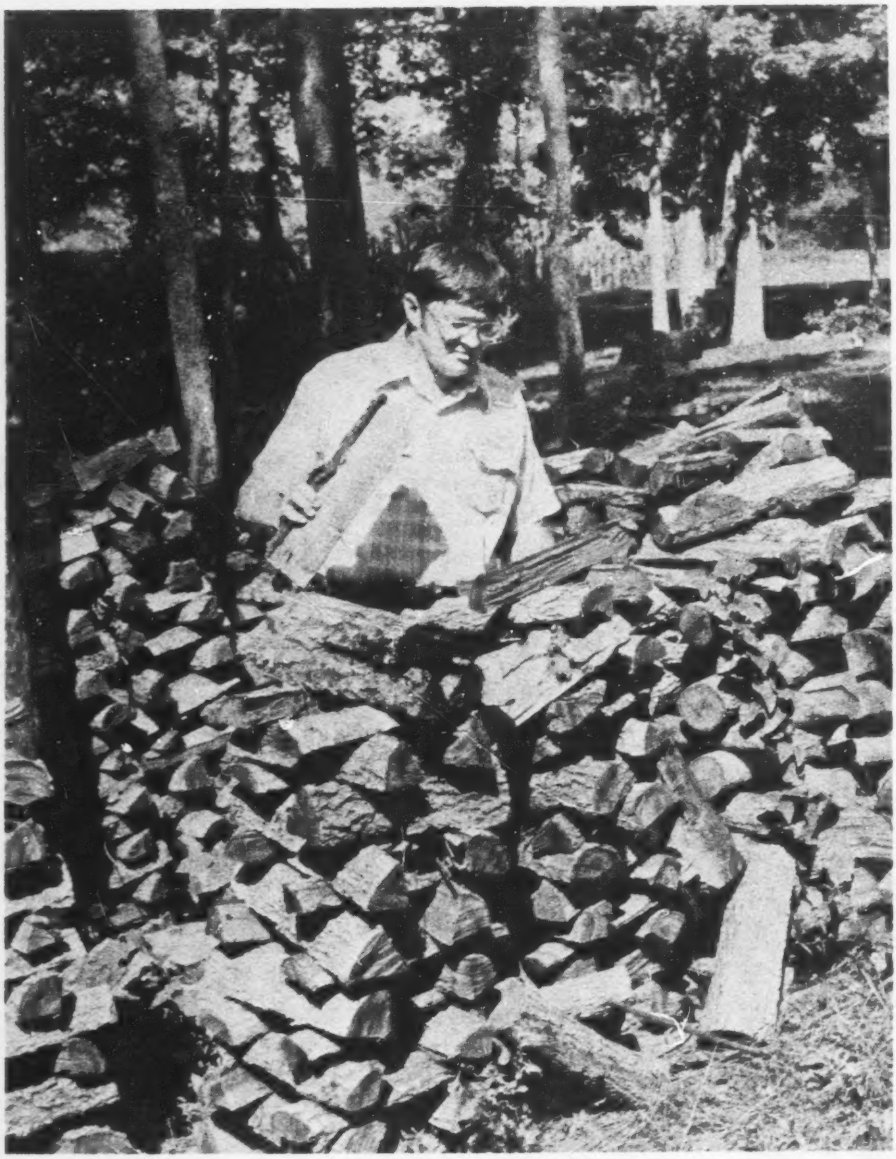
Pine forest management can also benefit from the demand for firewood. The removal of undesirable competing hardwoods from existing stands tend to favor the growth of the remaining pines to merchantable size. By the same token, as natural stands are harvested for pine sawtimber and pulpwood, there is most often a substantial residue of cull hardwoods that must be disposed of if, the pine stands are to be regenerated by plantation or seed tree methods. Because of the high cost of removing these competing hardwoods, many landowners are reluctant to make the necessary investments for improving and regenerating pine stands. With a cash return from selling their cull hardwoods as firewood, many landowners may now be able to practice the pine forest management which is needed if Georgia is to meet the growing demands of forest products industries on the forest resource.

## SUMMARY

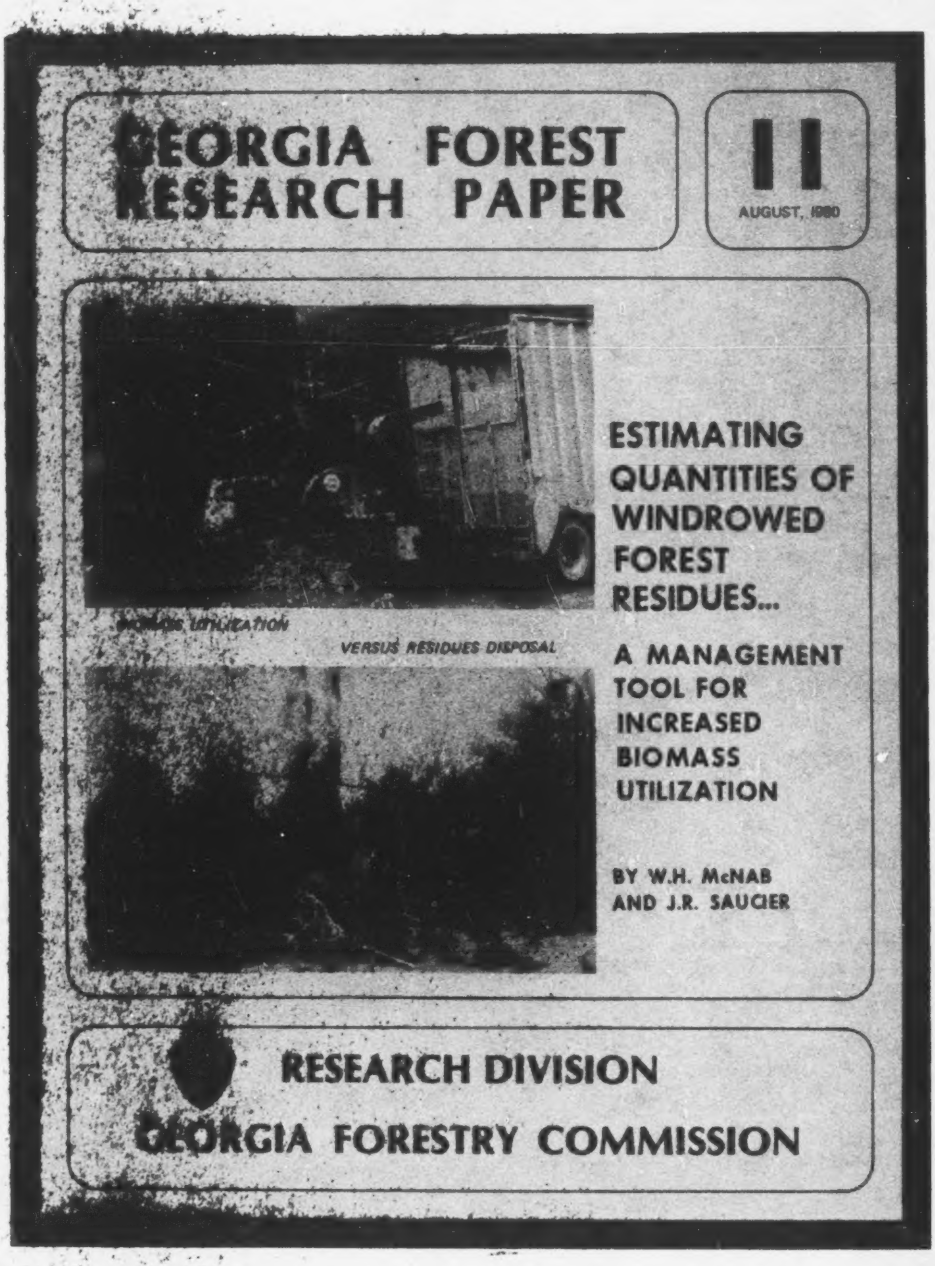
Georgians cannot remove themselves from the adverse economic influences of the scarcity and high cost of petroleum and other sources of energy. The use of wood for home heating can, however, give substantial relief in one high expense area and at the same time make greater use of a natural resource with which Georgia is abundantly endowed. The recent increase in the use of wood as a fuel for home heating can be expected to further increase. As home wood-burning equipment becomes more efficient and easier to use, the advantages of wood should become more apparent and the impact of its use even greater.



*This stand of cull hardwood represents the type of timber that is being used as fuel wood. It is the type material that cannot be marketed for the manufacture of lumber and other products and would otherwise remain in the forest as waste.*



*Well seasoned wood is the key to good efficiency in wood burning stoves. Here is one excellent method of curing wood. Note that all surfaces of the split hardwood are exposed to air.*



# GEORGIA FOREST RESEARCH PAPER

11

AUGUST, 1980

BIOMASS UTILIZATION

VERSUS RESIDUES DISPOSAL

## ESTIMATING QUANTITIES OF WINDROWED FOREST RESIDUES...

### A MANAGEMENT TOOL FOR INCREASED BIOMASS UTILIZATION

BY W.H. McNAB
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# ESTIMATING QUANTITIES OF WINDROWED FOREST RESIDUES

## A MANAGEMENT TOOL FOR INCREASED BIOMASS UTILIZATION

BY

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## INTRODUCTION

Windrowing is commonly used for site preparation in harvested clearcuts in Georgia; logging residues and unmerchantable standing trees are pushed into elongated piles (Figure 1). Windrowing is especially used on sites where naturally established pine has been removed from mixed pine-hardwood stands, leaving low-grade hardwoods which must be removed before pine regeneration. Often the landowner is not aware of the amount of hardwood present or how its use, such as whole-tree chipping for fuel wood, can provide additional income and reduce site preparation costs[1]. However, where the scattered residual trees have been concentrated into piles, the quantity available becomes apparent. At the present time, it may not be feasible to use the windrow material except possibly for firewood. By estimating the quantity and value of residues contained in the windrow, the landowner can easily evaluate the potential for greater harvest yields on similar sites. The purpose of this report is to describe a simple process developed for the landowner to evaluate his windrowed biomass.

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[1] Butts, P.M. and D.N. Preston. 1979. Whole tree chipping...A forest management tool. Ga. For. Res. Pap. No. 4, 8 p.

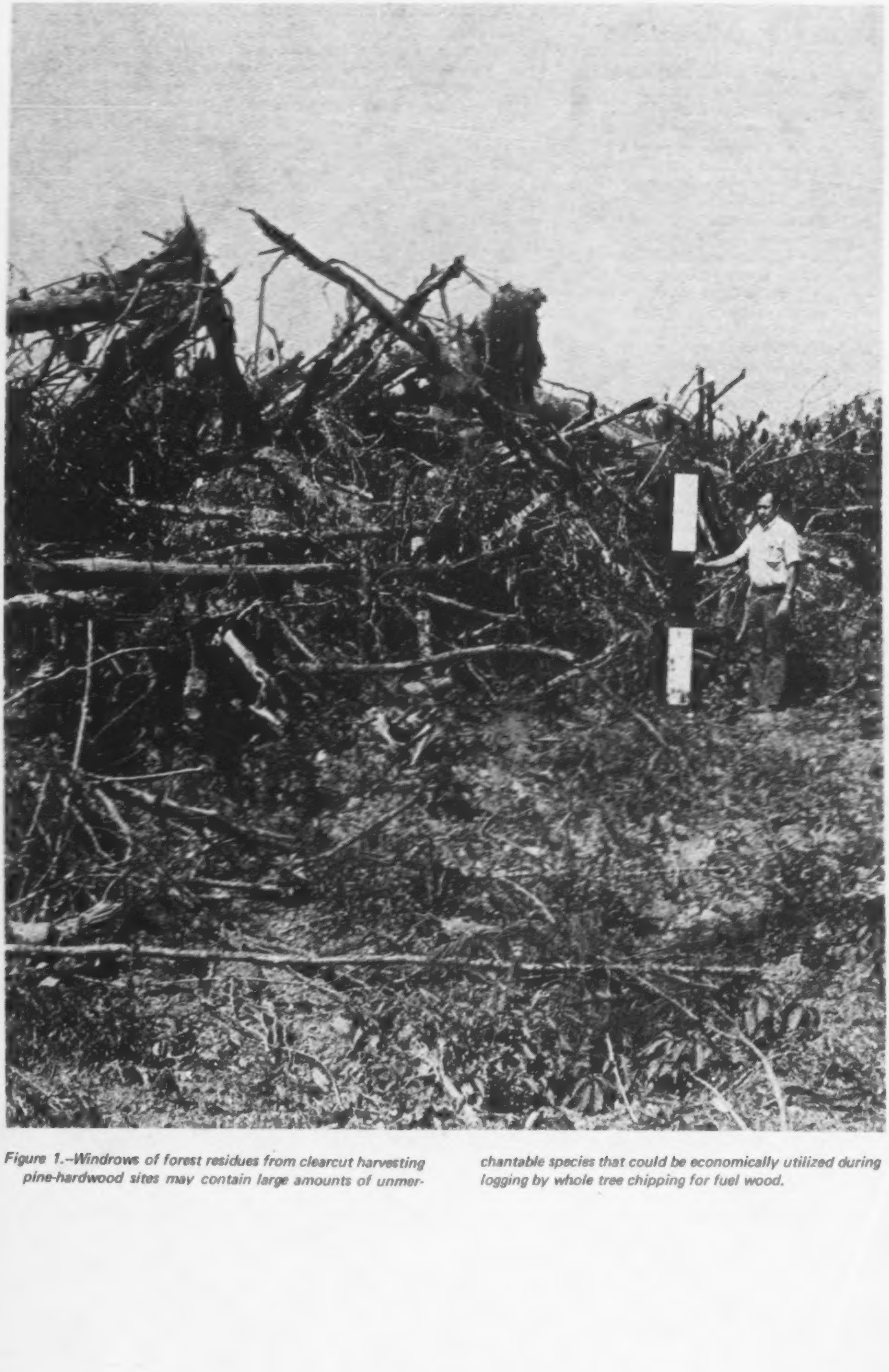

*Figure 1.–Windrows of forest residues from clearcut harvesting pine-hardwood sites may contain large amounts of unmerchantable species that could be economically utilized during logging by whole tree chipping for fuel wood.*

## STUDY PROCEDURES

Windrows were studied on three typical pine-hardwood sites on the Oconee National Forest: Sample points at 27 windrows were selected and 1-foot-wide paths were cut through the windrow with a chain saw. The exposed cross-sectional area of the windrow was measured, along with each piece of wood 0.25 inch or larger in diameter. A total of 54 transects were cut in windrows that ranged in size from 2 to 8 feet in height and 2 to 17 feet in width (Table 1). Other observations were also made including average size of windrow material and species composition. No residues were actually weighed, but the estimated weight of each 1-foot section was calculated from published values of air-dry density. These values were totaled to obtain the wood residue weight of the 1-foot-wide section through the windrow. This set of 54 values of wood residue weight along with other measurements made of the windrow at each sample point, was then analyzed. Our main purpose was to determine if certain easily measured characteristics of the windrow were correlated and could be used to predict the weight of wood present.

## RESULTS

We found that the amount of wood at a given sample point along a windrow correlated primarily with two factors:

1. The average diameter of wood residues greater than 3 inches observed at that point, and
2. The height of the windrow.

It is logical that these factors should be important. Stems and crowns of small diameter trees are not heavy enough to become tightly packed in the windrows by their own weight. Larger trees are heavier and tend to compress the windrow content into a more compact mass. However, as the height of the windrow increased, the total amount of wood residue tended to decrease because more holes and openings between the tree stems were present, which did not add to the total overall weight. A prediction equation was derived which expresses the relationship between wood residue diameter and windrow height as it affects the proportion of wood in the windrow. The equation can be intrepreted as predicting the proportion of solid wood present in a typical 1-cubic-foot section through the windrow.

*Table 2. –Dry weight of residue per cubic foot of windrow cross-sectional volume may be estimated from average size of residue greater than 3-inches in diameter on the windrow surface and average maximum windrow height.*

| Windrow | Residue diameter (in) | | | | | | |
|---|---|---|---|---|---|---|---|
| height (ft) | 4 | 6 | 8 | 10 | 12 | 14 | 16 |
| | | | | lb/ft$^3$ | | | |
| 4 | 3.0 | 6.4 | 8.6 | 10.0 | 11.1 | 11.8 | 12.4 |
| 5 | 2.7 | 6.0 | 8.1 | 9.6 | 10.6 | 11.3 | 11.9 |
| 6 | 2.6 | 5.8 | 7.8 | 9.3 | 10.3 | 11.0 | 11.6 |
| 7 | 2.4 | 5.6 | 7.6 | 9.0 | 10.0 | 10.8 | 11.3 |
| 8 | 2.4 | 5.5 | 7.5 | 8.9 | 9.9 | 10.6 | 11.2 |
| 9 | 2.3 | 5.4 | 7.4 | 8.8 | 9.7 | 10.6 | 11.0 |
| 10 | 2.3 | 5.3 | 7.3 | 8.7 | 9.6 | 10.4 | 10.9 |

## APPLICATION

Weight and volume of windrowed residues can be easily estimated after information is collected on the following:

1. Average diameter of residues
2. Average maximum windrow height
3. Average horizontal distance to windrow midpoint
4. Total length of windrow on the tract

As noted previously, residue diameter and maximum height are used to estimate

*Table 3. –Adjusted windrow cross-sectional volume may be estimated using average height and mid distance windrow width, as shown in Figure 2.*

| Windrow | Windrow width to center (ft.) | | | | | | |
|---|---|---|---|---|---|---|---|
| height (ft.) | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| | | | | Feet$^3$ | | | |
| 4 | 22 | 27 | 32 | 37 | 41 | 46 | 51 |
| 5 | 27 | 33 | 39 | 45 | 51 | 57 | 63 |
| 6 | 32 | 39 | 46 | 53 | 61 | 68 | 75 |
| 7 | 37 | 45 | 53 | 62 | 70 | 78 | 87 |
| 8 | 41 | 51 | 61 | 70 | 80 | 89 | 99 |
| 9 | 46 | 57 | 68 | 78 | 89 | 100 | 110 |
| 10 | 51 | 63 | 75 | 87 | 99 | 110 | 122 |

Table 1. Mean physical characteristics of windrows sampled on three pine-hardwood clearcut sites on the Oconee National Forest.

| Location | Windrows measured | Transects sampled | Windrow height | | | Windrow width | | | Cross-section profile area |
|---|---|---|---|---|---|---|---|---|---|
| | | | Mean | Minimum | Maximum | Mean | Mimimum | Maximum | |
| | Number | | Feet | | | | | | ft$^2$ |
| I | 6 | 6 | 3.4 | 2.0 | 6.0 | 6.7 | 5.0 | 11.0 | 24.4 |
| II | 17 | 33 | 3.9 | 1.8 | 8.1 | 10.6 | 3.4 | 16.8 | 29.8 |
| III | 5 | 15 | 3.3 | 1.8 | 5.3 | 9.3 | 2.5 | 17.1 | 23.4 |
| Mean | 28 | 54 | 3.7 | - - | - - | 9.8 | - - | - - - | 27.4 |

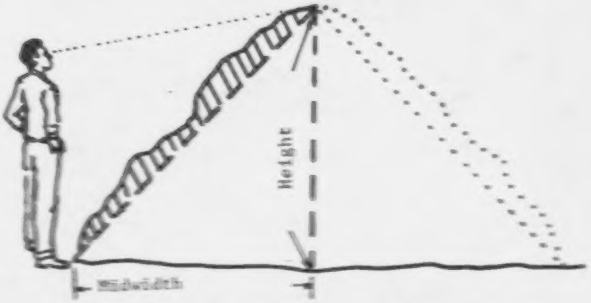

*Figure 2.—Windrow cross-sectional area was estimated in the field by assuming the pile was triangular shaped, and then determining maximum height and width to that point. This simple method usually underestimated the actual area by about 19 percent, due to surface irregularities (shaded portion). The opposite, unseen portion of the windrow was assumed to be symetrical with the observed portion.*

the volume of wood residue per cubic foot of windrow volume. This wood volume measurement may be changed to units of weight by multiplying the proportion by 35 pounds per cubic foot, an average air-dry density (12 percent moisture content) of hardwoods. Values of residue weight per cubic foot of windrow cross-sectional volume may be obtained directly from Table 2.

A measure of total windrow cross-sectional area (or volume, if a section 1-foot-wide is assumed) is then needed to determine estimated weight of residues through the entire windrow. Windrow cross-sectional area may be easily obtained at the sample points by determining height and horizontal distance to windrow center as shown in Figure 2, and then multiplying as if finding the area of a rectangle. Note also from Figure 2 that the typical windrow was not symetrical, and that an average of 19 percent more area was present in the windrow cross-sectional area as compared to the assumed symetrical proportions of a triangle. Table 3 may be used to determine the cross-sectional area of the windrow by using the height and midwidth distance at the sampling points.

The final step in determining weight of residue at a typical point along the windrow is merely to multiply the value of wood proportion obtained in Table 2 by the cross-sectional volume of the windrow obtained in Table 3. Of course, length of windrow on the entire tract would then be needed to estimate total biomass. An example of these calculations is shown below.

## EXAMPLE

In practice, estimates of mean residue diameter and mean windrow dimensions should represent the entire tract. These data may be obtained by systematically walking along one side of the windrow and stopping at predetermined distances, about every 500 feet. At least 30 samples should be obtained. Consider the following hypothetical data collected from 4 sample points along a windrow made from residues on a 10-acre tract:

| Sample point | Residue diameter | Windrow |  | Sample interval |
|---|---|---|---|---|
|  |  | Height | Mid distance |  |
|  | in. | ft. | ft. | ft. |
| 1 | 8 | 6 | 10 | 500 |
| 2 | 4 | 6 | 6 | 500 |
| 3 | 4 | 8 | 12 | 550 |
| 4 | 16 | 4 | 8 | 450 |
| Total | 32 | 24 | 36 | 2000 |
| Average | 8* | 6 | 9 | --- |

*Quadratic mean diameter should be used for greater accuracy in estimating average diameter.

From Table 2, we determine that weight of wood per cubic foot of windrow volume is 7.8 pounds per cubic foot. Using Table 3, windrow cross-sectional volume is found to be 68 cubic feet. Therefore, estimated weight per average foot of cross-sectional area of the windrow is equal to 7.8 pounds per cubic foot times 68 cubic feet equals 530 pounds per foot of windrow length. For the entire length of windrow, the estimated weight is 530 pounds per foot times 2,000 feet of length equals 1,060,800 pounds (530 tons) or 53 tons per acre.

## SUMMARY

This procedure for estimating weight of residue in a windrow is simple in concept and may be quickly and easily applied in the field. A wide range of sampling has not been completed, so the results should be interpreted as a rough estimate of the biomass present on a tract. The effect of soil in altering these relationships has not been determined, because residues were sheared with a sharp blade and very lightly raked on the Oconee Forest and no soil was found in the windrows. If soil was present, windrow dimensions maybe slightly larger and residue volumes could be slightly overestimated. If stumps are uprooted and pushed into the windrows, larger overestimates could occur. At the present time, this method should be considered primarily as a management tool to encourage greater residue utilization on other harvested tracts.

Currently, the best opportunity for greater utilization of unmerchantable hardwoods consists of total tree chipping for fuel wood. A simple method of estimating the quantity of fuel wood per acre before harvest is described in Georgia Forest Research Paper 7[2]. If the inventory cruise indicates the amount of potentially useable biomass is sizeable, it could be marketed when the merchantable portion of the stand is harvested.

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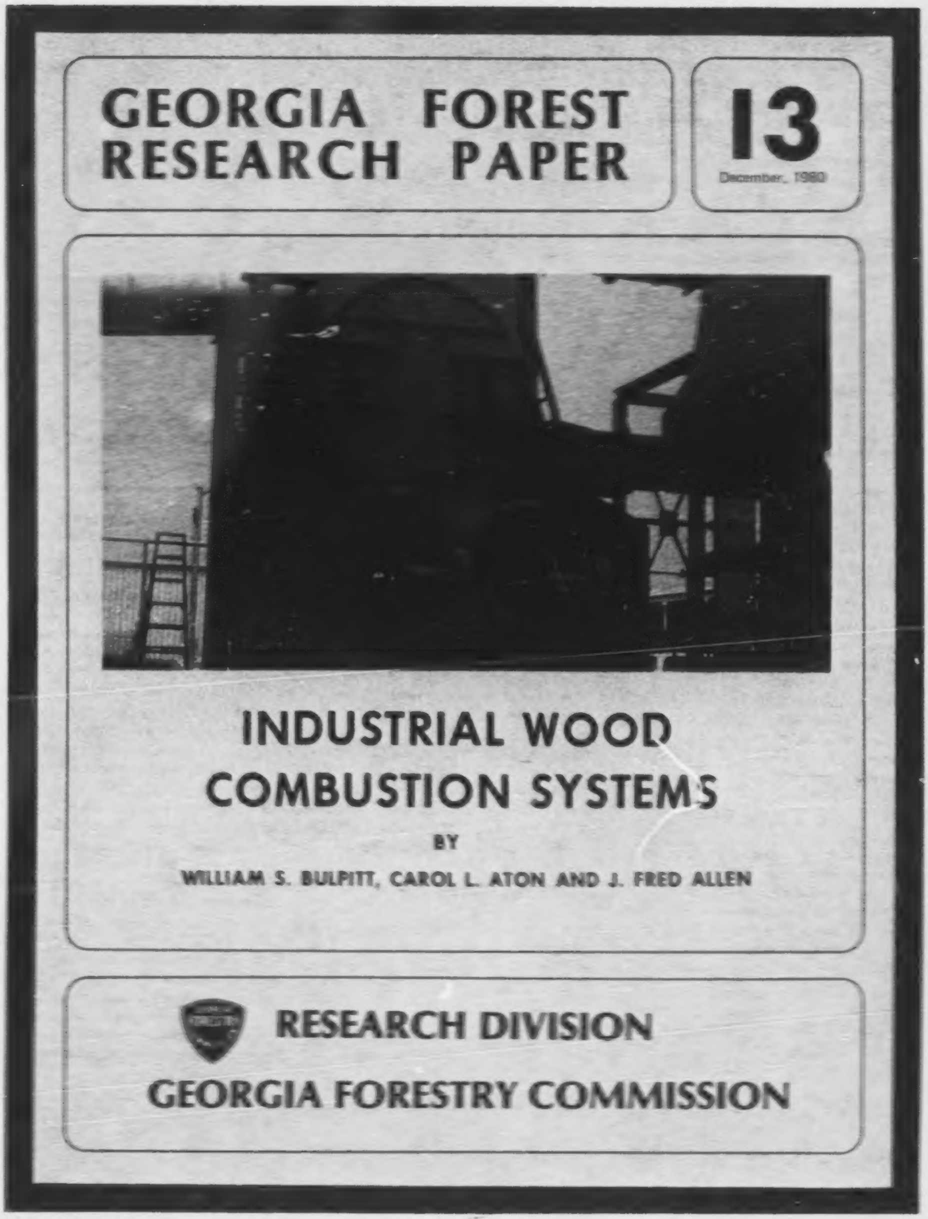
[2] Phillips, Douglas R. and Joseph R. Saucier. 1979. A test of prediction equations for estimating hardwood understory and total stand biomass. Ga. For. Res. Pap. No. 7, 8 p



# GEORGIA FOREST RESEARCH PAPER

13

December, 1980

# INDUSTRIAL WOOD COMBUSTION SYSTEMS

BY

WILLIAM S. BULPITT, CAROL L. ATON AND J. FRED ALLEN

RESEARCH DIVISION

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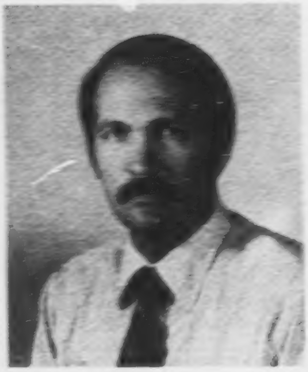

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# INDUSTRIAL WOOD COMBUSTION SYSTEMS

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AND J. FRED ALLEN

## BACKGROUND

Since steam power began to be an important source of energy in the eighteenth century, there has been a gradual evolution of hardware to the point we find ourselves today. The original fuel for steam production in this country was, of course, wood. As coal gained more widespread use, wood burning for industrial steam production became almost a lost art. In fact, coal and wood both nearly disappeared from the industrial scene in the southeast with the switchover to natural gas and oil as boiler fuels in the 1940's and 1950's. Wood burning systems were not ignored by all industries, however. During the past 50 years, the forest products industries have seen the gradual development of wood burning boilers from rather primitive pile burners to units that are capable of producing up to 50,000 lb/hr of steam at pressures that rival the steam pressures found in central utility plants.

Boilers may be divided into two general classes--firetube boilers and watertube boilers. As the designations indicate, in the firetube deign, the combustion gases travel through steel tubes passing through a water tank. In the watertube design, the water passes though steel tubes that are heated on the outside by the hot gases from the combustion process. Today many people have the tendency to dismiss the firetube boiler as an old-fashioned design, but this is not always the case. There are many applications where

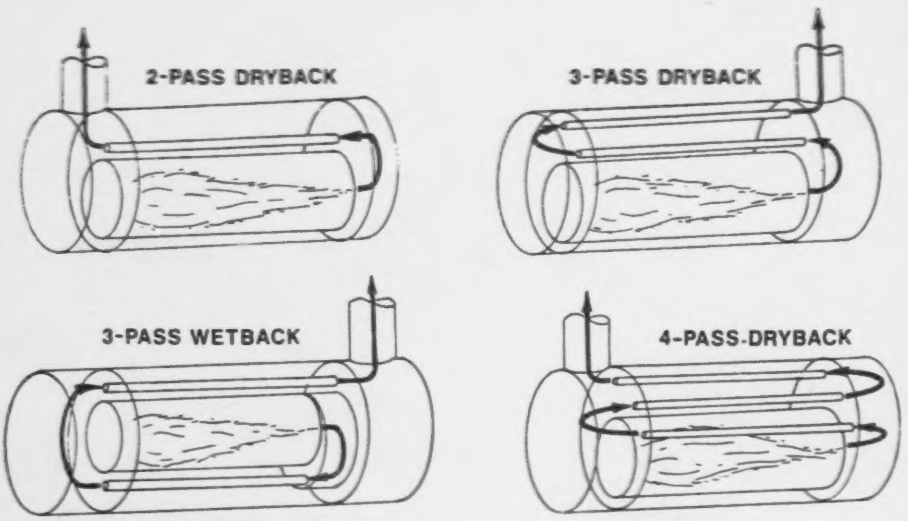


Figure 1

FIRETUBE BOILER GAS FLOW PATTERNS

the firetube unit has distinct advantages over a watertube unit, particularly in light and medium industrial applications. Figure 1 illustrates several configurations used in firetube boilers while Figure 2 illustrates a circulation pattern typical of a watertube boiler.

Besides the firetube and watertube classifications, boiler designations can be made in another manner: boilers can be "package" boilers or "field-erected" boilers. These designations can cause some confusion since virtually all wood burning units require some field erection. A package boiler generally can be shipped over land with normal transportation methods such as flat-bed truck or railcar. The major boiler components are in one assembly and can often be lifted right onto a simple foundation and piped into an existing system. As a result, the package boiler requires far less labor before startup than a field-erected unit. The field-erected unit often requires individual welding of boiler tubes and the entire fabrication of a steel framework. In other words, the boiler is completely built up at the job site from all the component parts, while the package boiler is nearly complete when it leaves the factory. Package boilers in the 100,000 lb/hr range have been shipped for gas/oil firing, but the larger combustion volumes necessary for wood units generally limit the top size for a wood fired package boiler to less than 50,000 lb/hr. As one might expect, field-erected boilers cost more than package boilers, and construction times are significantly longer.

## CLASSIFICATION OF WOOD COMBUSTION SYSTEMS

There are many different systems available today for burning wood in an industrial setting. Most of these systems fall into one of the following general classes:

Wood Fired Package Boilers
Suspension and Cyclone Burners
Fluidized Bed Combustors
Pyrolysis Systems
Gasification Systems
Field Erected Wood Boilers

Each of these classes will be considered in further detail.

## WOOD FIRED PACKAGE BOILERS

There are many manufacturers in the wood package boiler field today. In general, it can be said that the larger and perhaps better known manufacturers (Babcock and Wilcox, Combustion Engineering, Riley Stoker, Foster-Wheeler, etc.) are not really interested in building small (less than 50,000 lb/hr) boilers for light and medium sized commercial and industrial operations. This gap has been filled quite nicely by a number of smaller manufacturers; and as wood energy use has grown, the market has become more and more competitive.

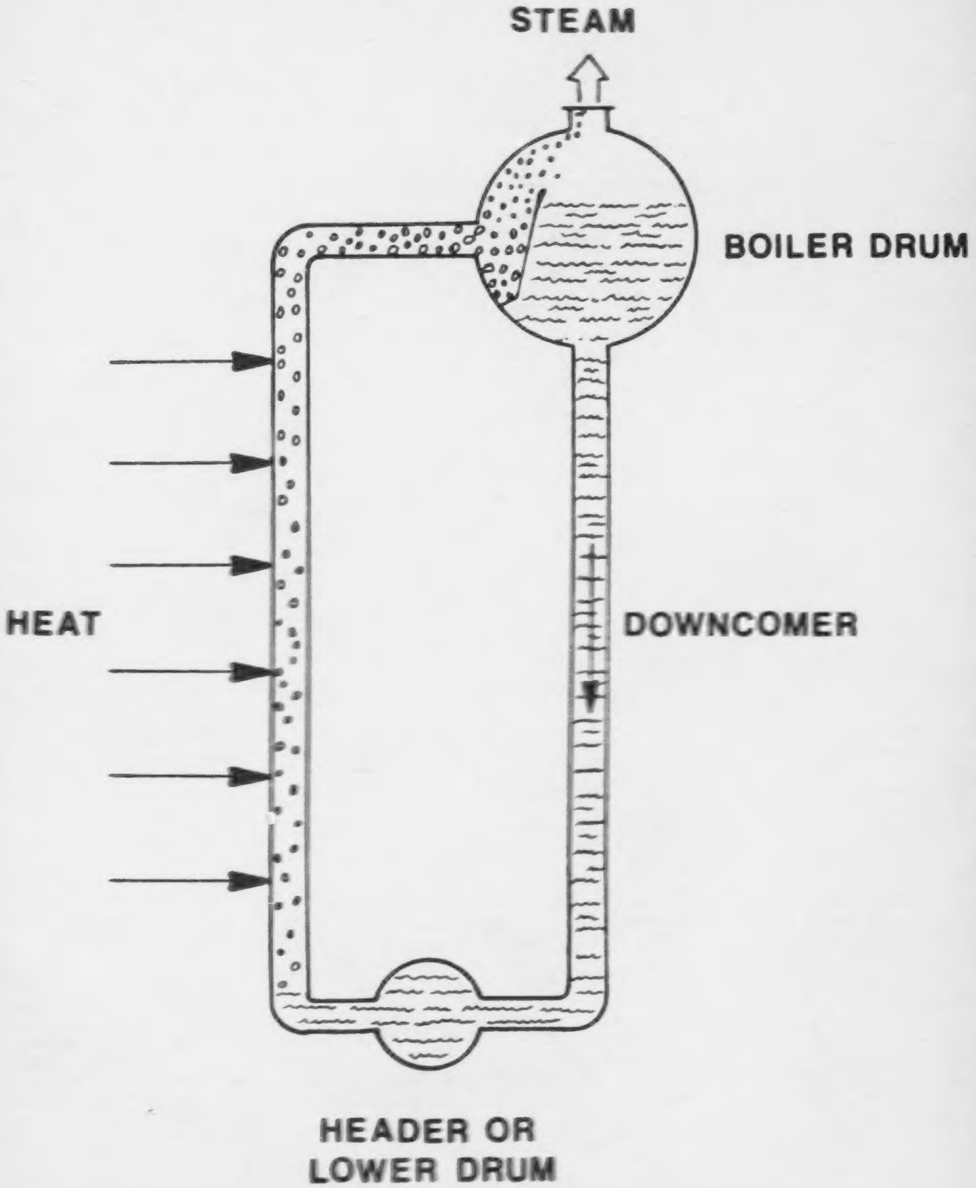


Figure 2

WATER CIRCULATION PATTERN IN A WATERTUBE BOILER

One of the older wood firing designs is the horizontal return tube (HRT) boiler. This type of unit was almost considered obsolete for a time, but in recent years it has seen a resurgence in sales. A typical HRT boiler is shown in Figure 3. The HRT is a firetube boiler which is basically a two-pass design. The steel boiler shell is supported by a refractory furnace, which helps these units to burn wet wood chips and residue ranging up to 60% moisture content. Operating pressures of HRT's are generally limited to 300 psi, and steam production is generally limited to 35,000 lb/hr or less. Some units are able to meet emission regulations using only mechanical collectors.

There are several other types of firetube wood boilers including compact three-pass types that perform well on furniture plant waste and other dry material less than 20% moisture content. These boilers may perform with a thermal efficiency up to 80%. Another type of firetube boiler is shown in Figure 4. It is equipped with an underfeed stoker capable of burning wood, coal, or combinations of the two fuels with oil and natural gas backup.

Several smaller manufacturers produce watertube boilers suitable for burning wood. One type that has been installed in more than 60 locations uses a refractory-lined cell burner with preheated underfire air. Most of the combustion takes place in the cell, and the hot flue gases are discharged into the watertube section.

The first cost of wood burning package boilers can be quite high, as shown in Figure 5. The cost curves in this figure are based on typical "turnkey" jobs installed by various boiler manufacturers and include fuel metering, controls, a limited amount of wood handling equipment, and air pollution control devices.

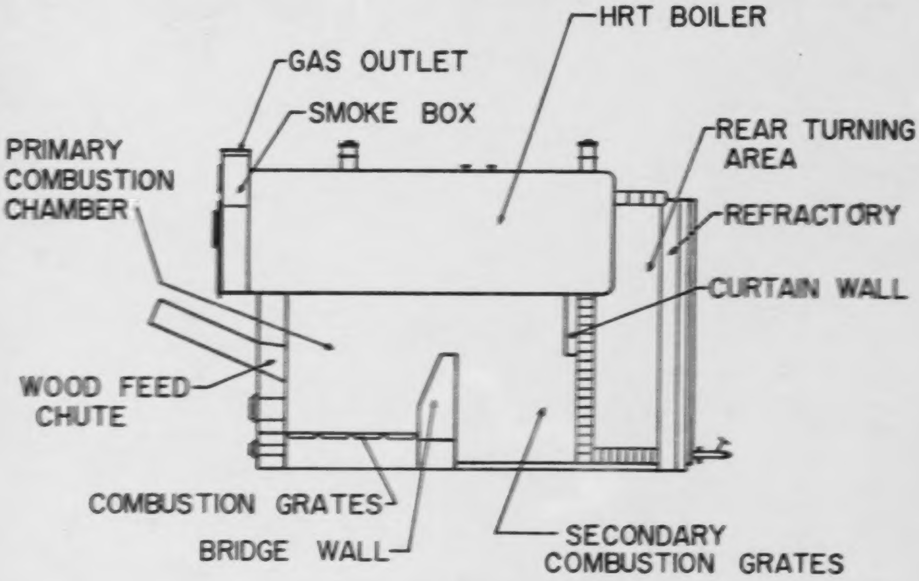


Figure 3

HRT BOILER FOR WOOD FIRING
(Courtesy Industrial Boiler Co.)

The less expensive range of boilers are generally the ones with the least flexibility with regard to the quality of the fuel that may be burned. Even the smallest package boilers require a given amount of solids handling equipment and control systems so that the cost per pound of steam is much higher for the smaller systems. As can be seen from Figure 5, a given size of wood package boiler will generally have a first cost of 3 to 4 times that of a comparable gas/oil boiler.

It may be difficult to retrofit an existing steam plant with a wood fired package boiler due to space limitations. Wood systems generally require a greater area than for gas or oil dictating a larger size for a given steam output.

The major conclusion to be drawn about wood fired package boilers is that, as a class, they represent a system that is considered fully commercial. The cost will be substantially higher than the traditional gas/oil package boiler, but the payback time due to fuel cost savings can be attractive.

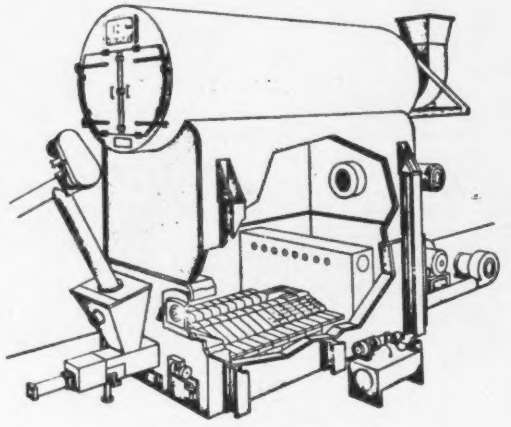


Figure 4

THREE-PASS WOOD BOILER
(Courtesy Combustion Service & Equipment Co.)

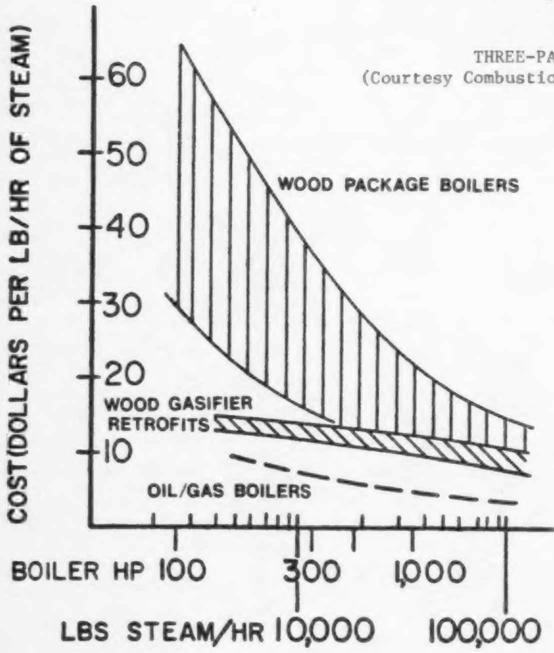


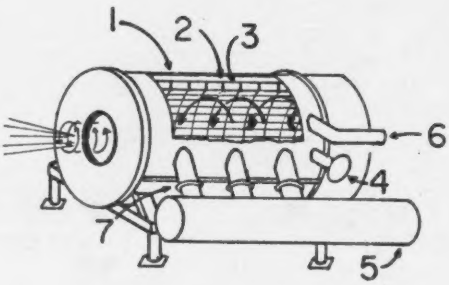
Figure 5

Cost of Wood Energy Systems

## SUSPENSION AND CYCLONE BURNERS

The cyclone furnace for burning pulverized coal has enjoyed widespread use on utility boilers for many years. The fuel is very finely ground and blown into the furnace almost as a gas. As a result, the combustion process is very efficient, and fly ash problems are easily dealt with.

Variations on the cyclone furnace concept have been developed for burning wood waste as well, but there are certain limitations that can hamper the feasibility for using these systems in many applications. The wood residue must be dry, and it must be hammermilled or hogged to fairly fine particles. In spite of these requirements, several companies have placed a number of these units in industrial plants, largely in the forest products industry. They have been used for firing directly into boilers, for product drying in rotary dryers, and for lumber dry kiln and veneer dryer applications. A typical cyclone burner is shown in Figure 6. In this particular unit, wood residue is blown tangentially through a series of manifolds from a pneumatic conveying system. Ash must be removed from the combustion chamber periodically, but otherwise the operation is fairly automatic. Cyclone wood burners generally range from 5 million Btu/hr to 60 million Btu/hr in single units.



(1) Insulation
(2) Air Plenum
(3) Refractory
(4) Auxiliary Burner
(5) Combustion Air Manifold
(6) Fuel Inlet
(7) Butterfly Valve

Figure 6
A Typical Cyclone Burner

## FLUIDIZED BED COMBUSTORS

The fluidized bed combustor has enjoyed much publicity over the past several years, particularly as an alternate combustion system for coal burning. Basically, a fluidized bed relies on a combustion chamber that has many holes drilled in the floor through which underfire air passes. This air blows through the "bed" which consists of small particles of sand, limestone, or other solid material. The bed is kept in suspension by the fans and is heated initially by an auxiliary fuel. When the bed reaches a temperature sufficiently high to ignite the fuel to be burned, the auxiliary fuel can be shut off and the solid fuel introduced. The turbulent mixing action of the hot bed material helps ensure that the fuel is burned completely.

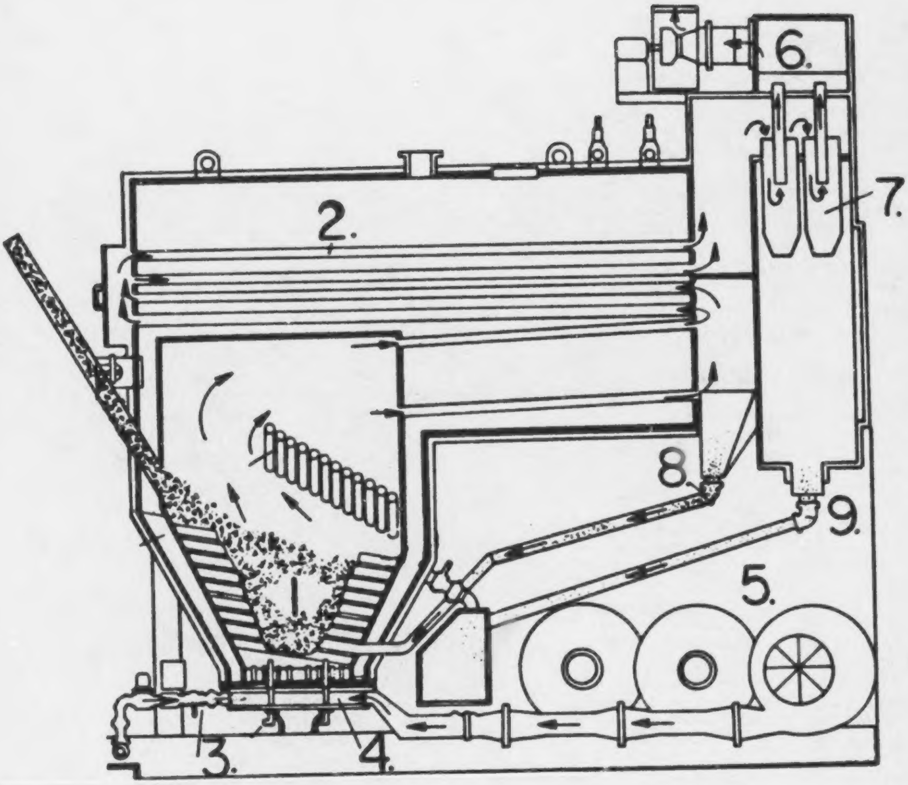
In wood burning systems, the fluidized bed combustors have shown promise as devices capable of burning wet fuels or fuels of irregular sizes and shapes. In addition, other waste materials such as carpet scraps and peanut shells may be burned in conjunction with the wood. Several companies are actively marketing various fluidized bed systems, and many units have been operated successfully in the forest products industry. Possible drawbacks include relatively high first cost, maintenance requirements greater than a conventional boiler for the same capacity, and high power requirements for the fans.

One design of fluidized beds used for wood firing is shown in Figure 7. This unit is compact and is installed as a package unit. Gas and oil auxiliary fuel, provided manually, is necessary for startup. A multiclone collector is used for pollution control. The advantages to fluidized beds for wood waste are the possibility of burning wet fuel of inconsistent sizes and shapes. It may be expected that the fluidized beds require higher maintenance than conventional wood burners, and that more highly skilled operators may be necessary to operate them.

## PYROLYSIS SYSTEMS

Pyrolysis can be defined as burning without oxygen. The process involves the physical and chemical decomposition of solid organic matter caused by the action of heat in the absence of oxygen. Wood can be pyrolyzed to produce charcoal, and coal can be pyrolyzed to produce gas. Due to the intense heat in a pyrolytic reactor, complex organic compounds can be broken down into simpler chemical products. These products include liquids, gases, and carbon char residue.

Various types of pyrolysis processes have been developed in recent years by many different companies. One of their goals has been the production of useful fuels from municipal solid waste (MSW).



(1) Fluidized Bed
(2) Firetube Heating Surface
(3) Gas Train
(4) Oil Train
(5) Forced Draft Fans
(6) Induced Draft Fan
(7) Cyclone Collector
(8) Carbon Reinjection
(9) Ash Disposal

Figure 7

A Fluidized Bed Suitable for Wood Firing
(Source: Johnston Co.)

However, limiting the feedstock to purely organic matter, such as wood waste or agricultural residues, simplifies the problem of dealing with large quantities of refuse. Figure 8 shows a pyrolysis system that has been successfully operated at Georgia Tech on wood chips. The system can produce varying amounts of oil, gas, and char according to the control configuration. Energy content of the products, of course, depends on the feedstock; but in general, the heating value of the oil is approximately 9,000 Btu/lb, heating value of the gas produced by the pyrolysis system varies from 3,200 Btu/lb to 4,500 Btu/lb and the heating value of the char varies from 12,300 to 13,500 Btu per pound.

Cost data for wood pyrolysis systems are difficult to obtain since the systems currently available are still largely in the prototype stages. The systems tend to be rather complicated, and as a result, they can be expensive. The attractive feature of the pyrolysis system is the possibility for sale of a high value product (char), but the purchaser should be quite certain about the existence of a market before investing in a pyrolysis system.

## WOOD GASIFIERS

The transformation of solid biomass into a gaseous fuel is not a new concept, but the idea has realized a renewed interest over the past several years. In the true sense, wood gasifiers are a subset of the wood pyrolysis units discussed in the previous section.

There are many different equipment configurations in use for wood gasification, but the units that are generating the most interest today are the air gasifiers. These gasifiers typically pass approximately 25% of theoretical combustion air through a glowing char bed. Several chemical reactions take place that result in a low heating value gas of 100 to 200 Btu/ft$^3$. Both of these gases, of course, have energy densities much lower than natural gas (1,000 Btu/ft$^3$), but the gas can still be a useful fuel for close-coupled applications.

There has been considerable interest recently in wood gasification as a retrofit technology for conventional gas/oil fired boilers. A low Btu burner can be substituted for the existing burner and fired with the "producer" gas. Some derating of the boiler would occur and the severity of this derating would depend on the particular design of the boiler.

The main problem associated with wood gasifiers is undesirable constituents in the gas including certain tars and acids. These have a tendency to condense in

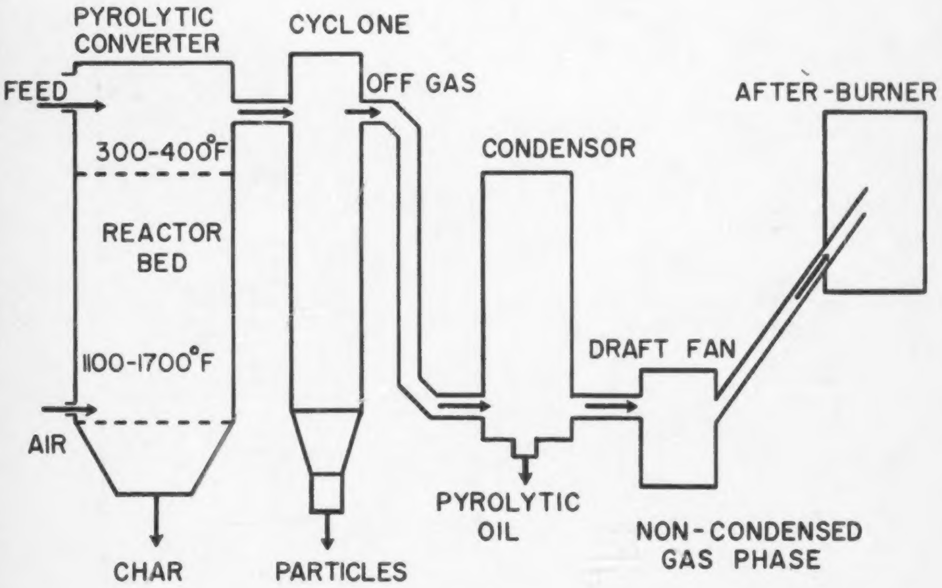


Figure 8

Pyrolysis Process
Georgia Institute of Technology

pipes and burners if the gas is allowed to cool or if the gas is not "scrubbed" as it exits the gasifier. These undesirable properties and grate slagging or burnout have been the most formidable problems researchers have faced.

The several concepts being developed for gasifiers at present include updraft gasifiers, downdraft gasifiers, cross flow gasifiers, and fluidized bed gasifiers. Figure 9 shows an updraft gasifier, but the same basic principles are involved in all units.

The gasifier vessel is filled with wood chips and a small fire is started on a grate above the ash hopper. Just enough air is introduced into the unit to support a glowing bed of coals. Steam may be injected into the bed to promote the formation of hydrogen ($H_2$) and to control grate temperature. In the reduction zone, the hot gases from the combustion process are partially reduced to carbon monoxide (CO), a low heating value gas. The products then pass into a pyrolysis zone where the infeed first gives up its volatile gases.

In the top section of the updraft unit, a drying process occurs wherein the exiting product gases give up some of their heat to the infeed. The gas is drawn off at the top of the unit and piped to a burner or engine for final combustion. Due to the various gasifier configurations being developed by different manufacturers, the gases produced differ somewhat in their contents.

In general, the main barriers to full scale commercialization of gasifiers include the following:

1) Lack of long term operational experience by current manufacturers
2) Potential problems in piping and burners resulting from tars and other liquids in gas
3) Slagging of grates due to ash contained in wood
4) Requirements for operator attention

One of the most attractive aspects of wood gasifiers is price. As mentioned earlier, package wood boilers may cost 3 to 4 times as much as the natural gas/fuel oil boiler that has been the mainstay of the commercial market for the past thirty years. Cost figures indicate that gasification systems can be retrofitted to an existing gas/oil burner for substantially less than the cost of a new wood system.

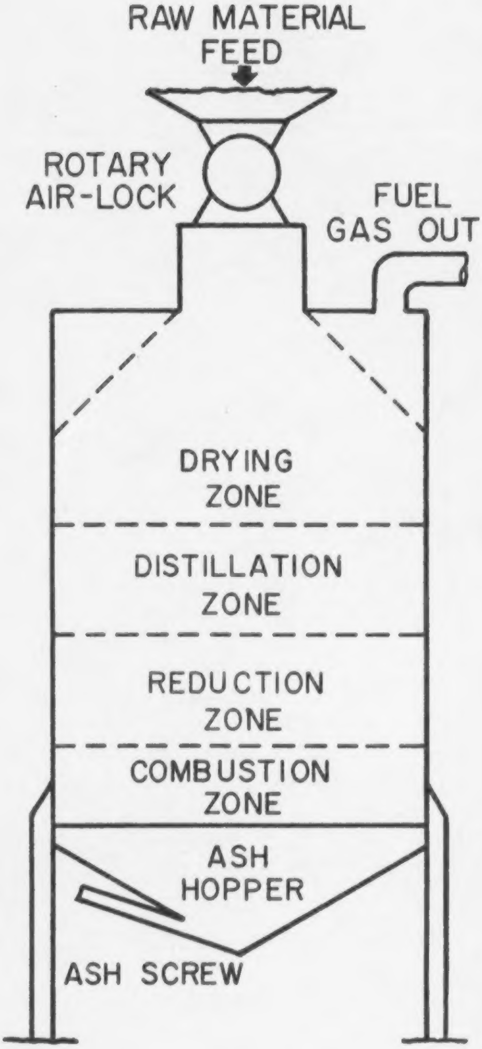


Figure 9

UPDRAFT WOOD GASIFIER

## FIELD-ERECTED BOILERS

The last category of wood burning systems considered here is probably the most specialized. This category is field erected wood burning boilers, and each application is very site specific. Due to the labor intensive nature of the field erected boilers, they are generally much more expensive than small package boilers: most have a capital cost of at least $35 per lb/hr of steam produced. Industrial users with a small or medium size steam requirement will probably stay away from the field erected units. Many paper mills in this country have large "bark" or "combination" (bark plus oil and gas firing) boilers capable of producing 400,000 lb/hr to 500,000 lb/hr of superheated steam for process use and electric power generation. Operating pressures may exceed 1200 psi.

Virtually all field erected boilers are watertube boilers and most use steam drums to separate the water and steam. Most units in use today for burning wood employ some form of traveling grate or stoker feed. Entrained particulates can be a problem with these units, so some form of collector is necessary to meet air pollution codes. Units of greater than 250 million Btu/hr input generally fall under stricter regulations than the smaller boilers and are thus subjected to "best available control technology" which can mean mechanical collectors, wet scrubbers, or even baghouses.

Large field erected boilers require full time operating crews and a great deal of maintenance. They are usually only cost effective in 24-hour-per-day operations since constant startup and shutdown of these units results in insulation cracks and refractory damage. There are far fewer companies building these large boilers than the package units discussed previously, and the permitting and construction processes can easily require 3 to 4 years. A typical field erected boiler is shown in Figure 10.

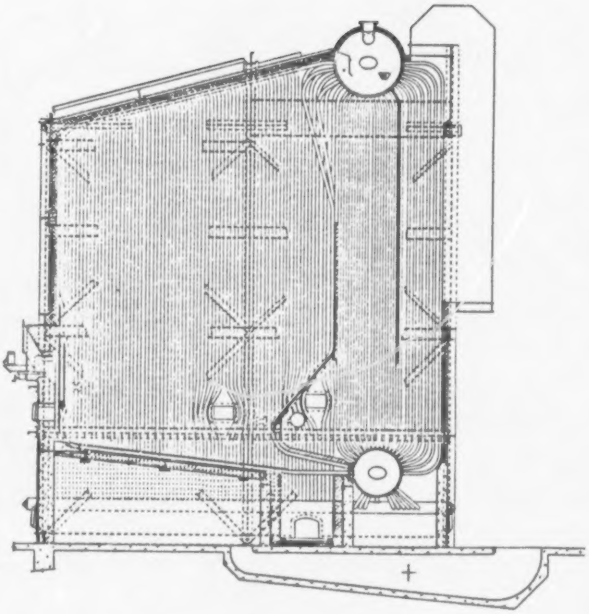


Figure 10

WOOD WASTE BOILER WITH WATER-COOLED GRATES
(Courtesy E. Keeler Co.)

## ALCOHOL PRODUCTION

## FROM WOOD

Methanol and ethanol are proven liquid fuels for transportation, particularly as alcohol-gasoline mixtures in autos. To reduce foreign oil dependence, much research emphasis has been placed on the use of ethanol produced from biomass crops and residue. Methanol, also known as wood alcohol, is a relatively inferior liquid fuel compared with ethanol. Ethanol has higher Btu content, is less toxic than methanol, is miscible with gasoline, and burns well without major modification to the engine. Also, both the initial capital investment and the size of the plant required to produce methanol are considerably larger than those required for ethanol.

Much of the recent work for the production of ethanol has focused on the use of food-based products such as sugar, corn, and other grains. Wood, corn stalks, and other plant residues, however, are more attractive raw materials since they are not part of the traditional food chain for man.

Production of ethanol from wood is an old concept. Figure 11 illustrates the process flow diagram. During World War II, a number of such plants were in operation in Europe. As single-product operations, these plants were not competitive with chemical plants based on an abundant supply of cheap petroleum as the feedstock.

A more desirable approach for producing ethanol from wood is an integrated multi-product plant where all components of wood--cellulose, hemi-cellulose, and

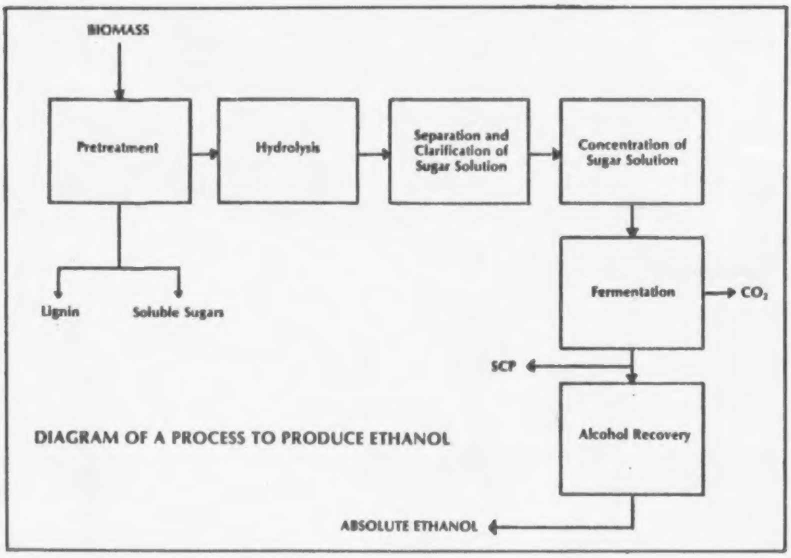

BIOMASS
Pretreatment
Hydrolysis
Separation and Clarification of Sugar Solution
Concentration of Sugar Solution
Lignin
Soluble Sugars
Fermentation
CO$_2$
SCP
DIAGRAM OF A PROCESS TO PRODUCE ETHANOL
Alcohol Recovery
ABSOLUTE ETHANOL

Figure 11

GENERAL BLOCK DIAGRAM OF A PROCESS TO PRODUCE ETHANOL

lignin--are processed, resulting in a number of valuable by-products. Lignin can be pyrolyzed into phenols, char, oil, and a combustible gas. Hemi-cellulose can be converted into pentose and hexose sugars, where the pentose can be used as a starting material to produce furfural, xylitol, single-cell protein, and also, to some extent, ehtanol. Cellulose can be hydrolyzed to produce glucose, which then can be fermented to produce ethanol, carbon dioxide, and yeast.

The first stage of operation is pretreatment during which lignin is separated from the biomass and hemi-cellulose is hydrolyzed into soluble sugars. The next stage of operation involves hydrolysis of cellulose into glucose, clarification of the solution, and concentration of the sugar solution. The third stage of operation includes fermantation of glucose into ethanol and separation of yeast. The final stage of operation is the recovery of alcohol and the production of absolute ethanol, which can be used in gasohol.

The production of ethanol can be economical only if

1) The raw material is available without large fluctuations in price
2) By-products can be sold
3) The crude oil price keeps going up, and
4) Liquid fuel becomes less available

Production of ethanol could play a very important role in reducing the dependence on the foreign supply of liquid fuel.

On the long-term basis, the ethanol produced from the renewable raw materials such as wood, agricultural residue, and crop residue, looks very promising as compared with high-priced, nonrenewable foreign crude oil.

## WOOD COMBUSTION

Combustion is the rapid chemical combination of oxygen with the elements of a fuel that will burn (Babcock and Wilcox Co., 1972).

In general, the combustion of wood can be separated into three stages. During the first stage, moisture from the fuel is evaporated. The second stage involves raising the fuel temperature to the point where volatiles are given off and combusted. The final stage is the combustion of the fixed carbons. All stages occur simultaneously in the combustion process.

## PROPERTIES OF WOOD FUEL

Dry softwoods, because of their higher resin and lignin content than hardwoods, have a higher heating value of approximately 9,000 Btu/lb. The heating value of dry hardwood is approximately 8,400 Btu/lb. Wood has a typical ultimate analysis as follows: Carbon 51.4%, hydrogen 6%, and ash 1.5%; and a proximate analysis as follows: volatile material 78.1%, fixed carbons 20.4%, and ash 1.5%. Sulfur content is essentially zero.

Properties of wood fuel vary widely, however, chiefly due to its moisture content. Wood fuel also comes from a variety of sources, and the range of particle size and form produce variation in the bulk density. Table 1 gives typical wood fuel values.

## FUEL MOISTURE CONTENT

Moisture content is generally measured on a dry basis or on a wet basis. The dry basis is commonly used by the forest products industry, whereas fuel and combustion engineers use the wet basis measure.

The dry basis measure is the fractional water content or the weight of the water in the sample divided by the sample weight when dried.

$$\text{Moisture content \% (Dry)} = 100 \left(\frac{\text{Weight of wet sample - Weight of dry sample}}{\text{Weight of dry sample}}\right)$$

Example: A one-pound sample which is half water and wood would have a wet weight of one pound. A dry weight of one-half pound a M.C. (dry) of 100%.

The wet basis measure assumes that the weight of the wood and water to be 100 percent and is the weight of water in a wood sample, divided by the weight of dry wood plus the weight of water.

$$\text{Moisture content \% (Wet)} = 100 \left(\frac{\text{Weight of water}}{\text{(Weight of dry wood + weight of water)}}\right)$$

Example: A one-pound sample which is found to be one-half pound of wood and one-half pound of water upon drying and weighing has a moisture content of 50%.

The conversion of moisture content can be accomplished by the following:

Wet to Dry

$$\text{Moisture Content (Dry)} = 100\left(\frac{\text{M.C. Wet}}{\text{100-M.C.Wet}}\right)$$

Dry to Wet

$$\text{Moisture Content (Wet)} = 100\left(\frac{\text{M.C.Dry}}{\text{100+M.C.Dry}}\right)$$

The moisture content of the fuel has an important effect upon the actual heat content of the fuel. The actual heat content of a given fuel can be determined as follows:

$$\text{Actual Heat Content} = \frac{\text{100-Wet M.C.}}{100} \text{ X Oven Dry Heat Value}$$

Moisture content of fuel is an important criteria in the design of a wood combustion system. Whereas wood boilers designed to burn green wood can usually burn dry wood, the reverse is seldom true. Analysis of available wood supply as to quantity, moisture content, and form is recommended before making the final decision on which boiler to install.

Table 2 covers the normally encountered moisture content range.

Table 1.--Wood Fuel Properties

| Wood Fuel | Moisture Content: Wet Basis | Higher Heating Value | Bulk Density |
|---|---|---|---|
|  | Percent | Btu/lb | $lb/ft^3$ |
| Whole Tree Chips | 50 | 4,500 | 24.0 |
| Dry Planer Shavings | 13 | 7,800 | 6.0 |
| Green Sawdust | 50 | 4,500 | 20.0 |
| Dry Sawdust | 13 | 7,800 | 11.5 |
| Wood Pellets | 10 | 8,100 | 35.0 |

Table 2.--Wood Moisture Content

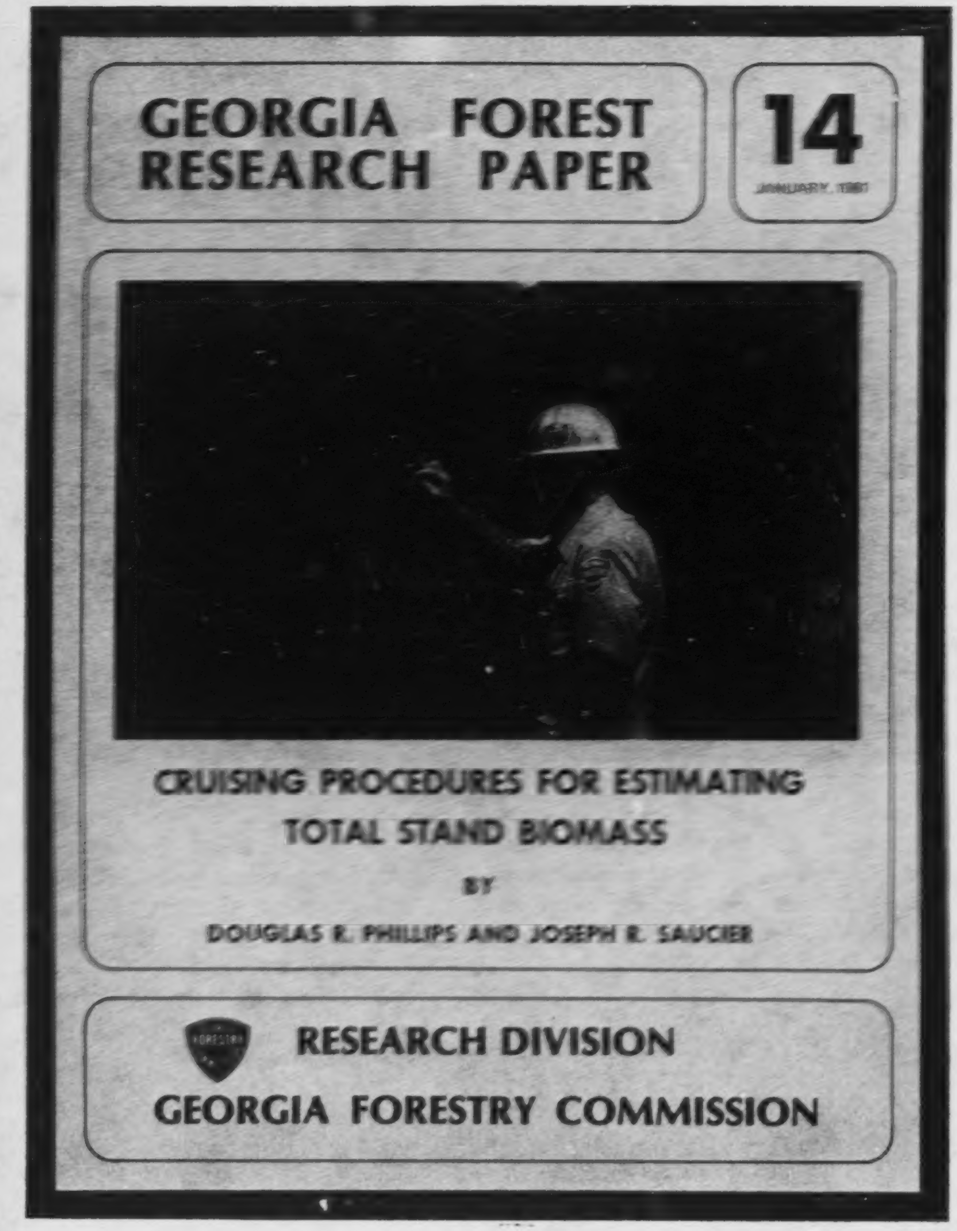
| Wet Basis | Dry Basis |
|---|---|
| Percent |  |
| 0 | 0 |
| 5 | 5 |
| 10 | 11 |
| 15 | 18 |
| 20 | 25 |
| 30 | 43 |
| 40 | 67 |
| 50 | 100 |
| 60 | 150 |

The chipper chips the complete tree including limbs and twigs, as well as separating the commercial material.

The high speed, rubber tired skidders, with hydraulic grapple, deliver the wood to the whole tree chipper. The skidder is capable of multi-stem skidding.

A feature of the feller buncher is that trees can be sheared at ground level which reduces the cost of site preparation and planting and leaves less waste material. It can handle several trees at once, piling them at a central location for skidding to the chipper.

The chip loader can group the trees, and place them where they can be engaged by power pressured rollers for entry into the the chipper.



# GEORGIA FOREST RESEARCH PAPER

14

JANUARY, 1981

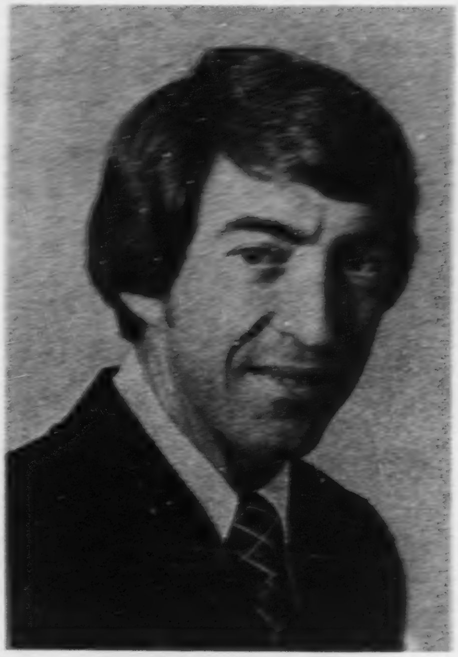
## CRUISING PROCEDURES FOR ESTIMATING TOTAL STAND BIOMASS

BY

DOUGLAS R. PHILLIPS AND JOSEPH R. SAUCIER

RESEARCH DIVISION
GEORGIA FORESTRY COMMISSION

# AUTHORS



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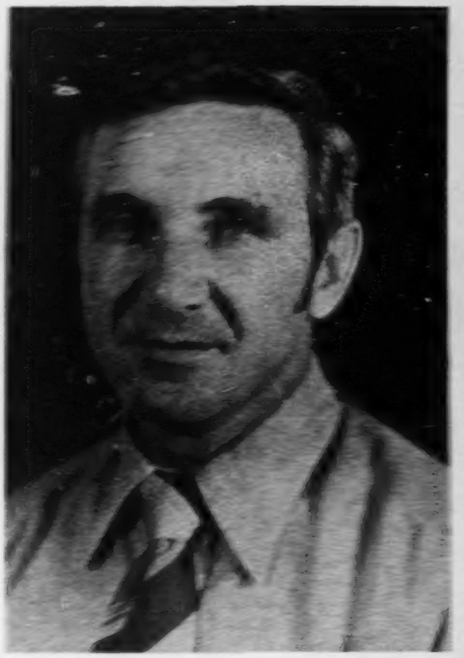

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# CRUISING PROCEDURES FOR ESTIMATING TOTAL STAND BIOMASS

BY

DOUGLAS R. PHILLIPS AND JOSEPH R. SAUCIER

## INTRODUCTION

Much of the commercial forest land in the South is occupied by small and poorly formed trees that will never be marketable as sawtimber. As fuelwood markets develop, landowners will be able to sell this poor timber to make room for thrifty stands of desirable trees. In such operations, some saw logs may be produced, but most of the material, including tree tops and small trees will be chipped. A method therefore is needed for estimating the biomass in such stands so that a fair market price can be established for the wood.

This report describes and evaluates three cruising methods for estimating total stand biomass in poorly stocked southern pine and hardwood forests. In these methods, biomass is estimated for trees 1-inch d.b.h. and larger. Weights of smaller stems are ignored.

## PROCEDURES

### Total Stand Biomass Cruising

On a 3.2-acre tract of mixed hardwoods in north Georgia we tested two estimation methods. The first method was a variable plot cruise with a 10-factor prism. Two service foresters from the Georgia Forestry Commission each cruised the same 10 systematically located plots in the stand. They tallied trees in seven classes: pine sawtimber, pine pulpwood, pine understory, hardwood sawtimber, hardwood pulp, hardwood understory, and cull hardwood. Basal areas in these classes were then used to predict total stand biomass with factors developed by Hughes (1978) as shown in table 1.

In the second sampling scheme, ten 1/20-acre fixed radius plots (radius = 26.3 feet) were systematically located throughout the stand. On each plot, all trees 1.0 inches d.b.h. and larger were measured, and species, d.b.h. to the nearest 0.1 inch, and total height were tallied. The weight of each tallied tree was predicted with regression equations available in the literature (Taras and Clark 1974; Clark and Taras 1976; Clark and Schroeder 1977; Clark, et al. 1980; Clark and Phillips 1980; Phillips 1977; Phillips 1981; and Wiant, et al. 1979). Weights were summed and converted to tons of biomass per acre by multiplying the total for each 1/20-acre plot by 20.

All trees larger than 1 inch in diameter were then harvested. Some saw logs were extracted at the landing and weighed separately on electronically operated platform scales. The remaining material was chipped with a commercial chip harvester. Chips were blown into a van and weighed on portable highway scales. Weights of sample loads were verified on local pulpwood scales. Some high stumps (higher than 0.5 foot) were left by the tree fellers, and some tree biomass was left on the site by the separator that was attached to the chipper. These components were measured and will be described later.

On a second tract of 31.5 acres of mixed pine and hardwoods in west Georgia we tested three methods of estimating total stand biomass. The first method was a prism cruise similar to the one used in the first stand. Twenty-seven 10-factor prism plots were systematically located throughout the stand.

The second method utilized was what we call "fixed radius ocular plots." All trees 1-inch d.b.h. and larger were tallied on 1/20-acre plots by 2-inch d.b.h. classes and by three broad species categories: hard hardwoods, soft hardwoods, and pine. Tree diameters and limits of the plots were estimated by eye. Twenty-seven plots were systematically located throughout the stand.

The third plot type was a "fixed radius detailed tally plot." All trees 5.0-inches d.b.h. and larger on a 1/20-acre plot were tallied by species, d.b.h. to the nearest tenth of an inch, and total height. Trees 1.0 to 4.9 inches d.b.h. were tallied on a 1/100-acre plot taken at the same plot center. Diameters and heights were measured. Fourteen such plots were systematically located throughout the stand.

As with the first stand, prism plot tallies were used in conjunction with biomass factors developed by Hughes (table 1) to predict total stand biomass in tons per acre. The weight of individual trees tallied on the fixed radius plots (both ocular and detailed) were determined by applying prediction equations available in the literature. Individual tree weights were summed to get plot weights, which were in turn converted to tons per acre.

Total trees 1 inch d.b.h. and larger in the second stand were chipped by a commercial operator, and chips were weighed on delivery at a local papermill. Again, some of the biomass was not removed from the site. The chip harvester had a separator that left about 8 percent of stand biomass on the site. And, some trees were intentionally left standing as shade trees since the site was to be converted to pasture. There were also some high stumps. These components were measured and will be described later.

## RESULTS AND DISCUSSION

### Stand Comparisons

The two stands we examined were similar in many respects. The first stand (the 3.2-acre tract in north Georgia) contained 1,096 trees per acre of which 124 were overstory trees greater than 5.0 inches d.b.h. and 972 were understory trees from 1.0 to 4.9 inches d.b.h. The second stand (the 31.5 acres in west Georgia) contained 1,178 trees per acre with 205 trees in the overstory and 973 in the understory (table 2). The first stand contained over 98 percent hardwoods, but the second stand was approximately 35 percent hardwood and 65 percent pine. For trees larger than 5.0 inches d.b.h., average d.b.h. was 9.2 inches in stand 1 and 8.1 inches in stand 2. For the same trees, average height was 62 feet in stand 1 and 58 feet in stand 2.

Table 1.--Biomass factors for converting prism cruise tallies to tons of biomass per acre for whole trees and tree components[1]/[2]/

| Tree size class | Total biomass | Stem (to a 4-inch d.o.b. top) | Saw logs (to 8-inch d.o.b. pine, 10-inch d.o.b.) hardwood | Topwood (from saw log to a 4-inch d.o.b.) | Fuelwood (topwood plus crown) |
|---|---|---|---|---|---|
| | -----------Tons of biomass/10 sq.ft. of basal area----------- | | | | |
| Pine sawtimber (9.0" d.b.h. & larger) | 15.2 | 12.5 | 10.0 | 2.5 | 2.7 |
| Pine pulpwood (5.0-8.9" d.b.h.) | 8.4 | 5.7 | -- | -- | 2.7 |
| Pine saplings (1.0-4.9" d.b.h.) | 5.3 | -- | -- | -- | -- |
| Hardwood sawtimber (11.0" d.b.h. & larger) | 17.5 | 11.5 | 7.9 | 3.6 | 6.0 |
| Hardwood pulpwood (5.0-10.9" d.b.h.) | 10.5 | 7.3 | -- | -- | 3.2 |
| Cull hardwood (5.0" d.b.h. & larger) | 12.5 | -- | -- | -- | -- |
| Hardwood sapling (1.0-4.9" d.b.h.) | 5.6 | -- | -- | -- | -- |

[1]/ After Hughes, McDavid. 1978. Estimating the aboveground biomass and its component timber products of the southern forest. In Energy in the southern forest. 27th Annual Symp., Louisiana State Univ., Baton Rouge, LA, p. 62-83.

[2]/ To determine stand biomass, multiply the number of tally trees in each tree size class by the appropriate factor. For example, if the average cruise of say 20 plots is 3 pine sawtimber trees, 4 pine pulpwood trees and 1 hardwood sapling tree, the estimated total stand biomass is: 3(15.2) + 4(8.4) + 1(5.6) =84.8 tons per acre.

Table 2.--Basal area and stand biomass estimates by three cruising methods for two stands in Georgia

| Stand no. | Size of stand | Stand component | Stems per acre[a] | Basal area estimates by cruise method: Prism plots | Basal area estimates by cruise method: Fixed 1/20-acre: Ocular tally plots | Basal area estimates by cruise method: Fixed 1/20-acre: Detailed tally plots | Stand biomass estimates by cruise method: Prism plots | Stand biomass estimates by cruise method: Fixed 1/20-acre: Ocular tally plots | Stand biomass estimates by cruise method: Fixed 1/20-acre: Detailed tally plots | Actual stand biomass |
|---|---|---|---|---|---|---|---|---|---|---|
| | Acres | | | - - - - - Sq. ft./acre- - - - - | | | - - - - - - Tons/Acre- - - - - | | | |
| 1 | 3.2 | Overstory | 124 | 63.0[b] | - - | 60.8 | 64.2[b] | - - | 62.1 | 59.7 |
| | | Understory | 972 | 35.5[b] | 27.5[b] | 31.1 | 19.8[b] | 17.8[b] | 19.8 | 19.1 |
| | | Total stand | 1,096 | 98.5 | - - | 91.9 | 84.0 | - - | 81.9 | 78.8 |
| 2 | 31.5 | Overstory | 205 | 61.1 | 71.5 | 77.8 | 70.8 | 68.5 | 64.7 | - - [c] |
| | | Understory | 973 | 31.9 | 27.7 | 27.2 | 16.2 | 20.3 | 20.3 | - - [c] |
| | | Total stand | 1,178 | 93.0 | 99.2 | 105.0 | 87.0 | 88.8 | 85.0 | 81.6 |

[a] from fixed actual tally plots.

[b] average of estimates by two cruisers.

[c] actual stand biomass was not separated by overstory and understory in this stand.

## Basal Area Estimates

Estimates of basal area per acre for the two stands by three cruising methods and by overstory, understory, and total stand are given in table 2. Basal area estimates for the three cruising methods were fairly consistent except for the overstory of stand number 2. In this stand the average basal area from 27 prism plots was 61.1 square feet per acre compared to 71.5 square feet per acre on 27 fixed ocular tally plots and 77.8 square feet per acre on 14 fixed radius detailed tally plots. The differences may be due in part to different sampling intensities.

Basal area estimates seem to be well correlated with tons of biomass per acre. For each square foot of basal area in the overstory there appears to be about 1 ton of biomass per acre. For each 3 square feet of basal area in the understory there are approximately 2 tons of understory biomass per acre.

## Stand Biomass Estimates

Fixed radius detailed tally plots yielded the most accurate estimates of biomass in the two stands. Prism plots and fixed radius ocular plots yielded poorer estimates. Fixed radius detailed tally plots overestimated actual stand biomass by about 4 percent. Prism plot estimates were high by 7.5 and 6.6 percent, respectively, for stands 1 and 2. The ocular plots in stand 2 overestimated total stand biomass by 8.8 percent (table 2).

Although the detailed tally plots were the most accurate, they are not necessarily the best. The amount of time required to tally detailed information on these plots was about 21 minutes, compared to 11 minutes on ocular plots and 4 minutes on prism plots. Thus, approximately 2 ocular plots and 5 prism plots can be taken in the amount of time required to measure one detailed tally plot.

A prism cruise using biomass factors by Hughes (table 1) does not include tree height as a variable. Thus, poor estimates can result if the factors are applied to very short or very tall stands and no adjustments are made. For example, on a 11.04-acre demonstration area set up by the Georgia Forestry Commission, virginia and shortleaf pines averaged only 50 feet tall although the diameters of dominant trees were 10 to 12 inches. Two foresters cruised the stand using 10-factor prisms to tally the trees marked to be cut. Applying Hughes' factors to their cruise data yielded biomass estimates of 72.1 and 73.1 tons per acre, respectively. When the trees marked to be thinned were harvested and weighed, we found that only 58.4 tons of biomass per acre had been removed. The cruise estimates were high by 23 to 25 percent. The same kind of error can result with any method that does not account for differences in tree height.

## Biomass Harvested

Not all of the biomass was removed from the two sites that were total-tree chipped in this study. The first tract (the 3.2-acre tract in north Georgia) produced 53.5 tons per acre of total tree chips and 14.5 tons per acre of saw logs (table 3). Another 10.8 tons per acre were left on the site as material returned to the site by the chip harvester separator (bark, twigs, and needles), as high stumps (above 0.5 feet), and as standing trees left on the site. The 68 tons of biomass per acre removed represented 86.3 percent of the available biomass on this site.

From the second area total tree chipped (the 31.5 acres in west Georgia), 73.8 tons of chips per acre were removed and 7.8 tons of biomass were left on the site (table 3). Saw logs were not cut on this tract. The 73.8 tons of biomass per acre removed represented 90.4 percent of the available biomass on this tract.

## RECOMMENDATIONS

1. When a quick estimate of stand biomass is needed, the best approach is to put in a series of 10-factor prism plots and use the biomass factors provided by Hughes in table 1. An individual prism plot takes only about 4 minutes to put in. If the sample is representative, the results are very acceptable. Our tests indicate that the Hughes factors which were developed in Louisiana tend to overestimate slightly in stands in the Southeastern United States.

As always, people who use a prism to cruise timber should be thoroughly trained in its use. For example, the cruiser should hold the prism over plot center and rotate his body around the prism rather than stand on plot center and rotate the prism around his body. The cruiser should take care to check a tree's critical angle (which determines its "in" or "out" status) at exactly 4.5 feet from ground level. And finally, he should make sure he holds the prism perpendicular to his eye. Borderline trees (those that appear to be just "in" or just "out") should be checked by pulling a measuring tape from plot center to the tree to check the tree's distance from plot center against its actual d.b.h. An acceptable alternative to this approach is to tally every other borderline tree.

Table 3.--Biomass removed as total-tree chips and saw logs and biomass remaining as residue from the chip separator, high stumps, and residual standing trees for two test areas in Georgia

| Test area | Size of test area | Total-tree chips harvested | Saw logs harvested | Residue from chip separator | Residual as high stumps[1] | Residual standing trees on test area | Total stand biomass |
|---|---|---|---|---|---|---|---|
| | Acres | | | | Tons/acre | | |
| 1 | 3.2 | 53.5 | 14.5 | 2.3 | 1.4 | 7.1 | 78.8 |
| 2 | 31.5 | 73.8 | ---- | 6.2 | 0.3 | 1.3 | 81.6 |

[1] stumps cut above 0.5 feet.

2. If one feels more comfortable with a fixed plot tally but does not need detailed biomass data by species and actual d.b.h., the best approach is to put in a series of 1/20-acre plots and tally trees by pine, hard hardwood, and soft hardwood classes and by 2-inch diameter classes. This type of plot takes about 11 minutes to put in and gives good accuracy. A person who uses this cruising method should have experience in estimating tree diameters or he should test his ability to estimate tree diameters by measuring a few trees on the first plot. Regression equations and yield tables for converting plot tallies to pounds and ultimately to tons of biomass per acre are available from the Utilization of Southern Timber Work Unit, USDA Forest Service, Athens, Georgia 30602.

3. If estimates of total stand biomass by species, d.b.h., and total height are desired, and if maximum accuracy is needed even at higher costs, then a series of 1/20-acre fixed radius detailed tally plots should be used. These plots require an average of 21 minutes to measure, but the tally on these plots is fairly straight forward and requires less judgment by the cruiser. Weight equations and tables needed to convert cruise data to weight for total trees by individual species are available from the Utilization of Southern Timber Work Unit, USDA Forest Service, Athens, Georgia 30602.

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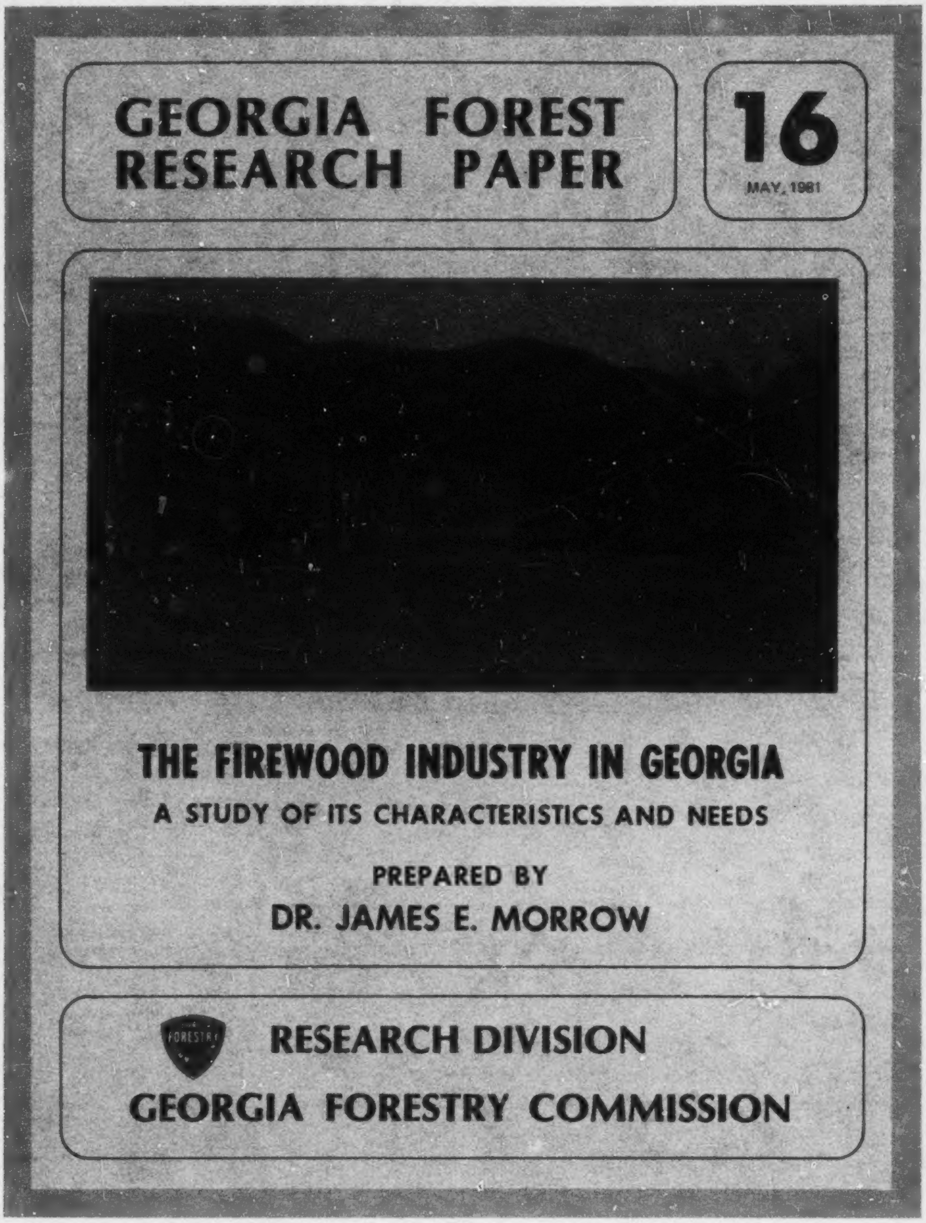
*A typical low quality hardwood stand suitable for total-tree chipping.*



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# THE FIREWOOD INDUSTRY IN GEORGIA

## A STUDY OF ITS CHARACTERISTICS AND NEEDS

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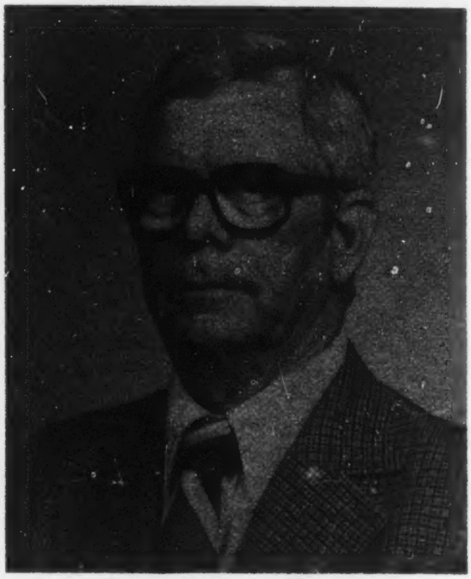

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# THE FIREWOOD INDUSTRY IN GEORGIA

## A STUDY OF ITS CHARACTERISTICS AND NEEDS

PREPARED FOR
GEORGIA FORESTRY COMMISSION

PREPARED BY
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## BACKGROUND AND PURPOSE

The recent growth in and the emphasis on the use of wood as an energy source or home heating has resulted in a number of studies on the demand for firewood and the characteristics of households that use it. Although not complete, there is a large base of data on who uses firewood, how much is used, and for what purpose. On the other hand, there is a minimum of information dealing with the industry that supplies the firewood for home consumption.

The Georgia Forestry Commission in its continuing program to promote the forestry industry recognized the need to better utilize those wood products that were the residue of some forestry operations and which frequently went to waste. Because these residue products were frequently highly suitable for firewood, the Commission explored ways of encouraging the use of firewood as a home energy source.

A study was completed on the demand for firewood by households in Georgia. The study gave indications that the supply of firewood was not uniform and that prices varied widely throughout Georgia. On the assumption that the use of firewood would be increased if households were assured of a ready supply at reasonable prices, the Commission elected to make a study of the firewood industry, the problems it faces, and what, if any, programs could be initiated to promote the growth of the industry.

The Georgia Forestry Commission and the Contract Research Division, College of Business Administration, Georgia State University conducted this study of the firewood industry. It involved personal interviews with 218 firewood dealers throughout Georgia. The interviews were conducted in December 1980 and January 1981. The data that were collected pertained to the operations of the firms in 1980.

## SURVEY FINDINGS

### General

This research report presents data on a number of factors that were explored during the interviews with 218 firms engaged in the business of selling firewood. Before presenting the detailed data on all of the factors, if will be useful to set forth a composite picture of a typical firm in the industry.

a. The firm sells firewood only at retail.
b. It is in the firewood business on a part-time basis only and operates in the months from October through February.
c. The firm obtains trees for firewood from within a 10 mile radius of the firm.
d. Most firewood is sold and delivered to homeowners in one-half cord loads.
e. Only 4 percent of the firms sell firewood at a discount in the non-heating season, and 40 percent increased their prices from 1979 to 1980 by generally 10 to 15 percent.
f. The median number of cords sold per firm per year was 40 and the average price was 82 dollars a cord.
g. Eighty-four percent of the firewood is sold in the 5-month period October to February.
h. Nearly all firms have only one or two employees.
i. The direct cash cost of preparing a cord of firewood was reported as 30 dollars or less by 55 percent of the firms.

### Detailed Analysis and Data Format

The following analysis of the information on the factors affecting the firewood industry is presented for the most part for the State of Georgia as a whole. The assumption was made however that there might be significant differences between the firms in the Northern counties and those in the Southern counties. In view of that possibility, the State was divided into regions. The 59 most Northern counties are in the Northern Region and are those counties in Georgia Forestry Commission Districts 1, 2, 3, 4, 5, 14, and 15. The remaining 100 counties are in the Southern Region. Separate data tables will be presented for the two regions when there is a notable difference in industry characteristics between them.

### Type of Firm - Wholesale or Retail

Selling firewood is primarily a retail business. As shown in Table 1, 79.7 percent of all firms sell at retail while only 19.4 percent sell both retail and wholesale. Two firms reported they were wholesale only. Both regions reported similar data.

### Monthly Participation in Firewood Business

One of the more significant aspects of the firewood industry on which additional information was needed was the proportion of firms that was in business during each month of the year. It could be anticipated that the level of sales would be lower in non-heating months, but the number of firms that operated during those months was unknown. Each firm was asked to indicate for each month whether it was in business full-time, part-

TABLE 1

DOES THE FIREWOOD FIRM SELL RETAIL OR WHOLESALE

| TYPE OF SALES | NUMBER OF FIRMS | PERCENT |
|---|---|---|
| RETAIL | 173 | 79.7 |
| WHOLESALE | 2 | .9 |
| BOTH | 42 | 19.4 |
| TOTAL | 217 | 100.0 |

TABLE 2A

MONTHLY PARTICIPATION IN FIREWOOD BUSINESS ON FULL-TIME BASIS
NUMBER OF FIRMS ENGAGED ON FULL-TIME BASIS

| | GEORGIA | | NORTHERN REGION | | SOUTHERN REGION | |
|---|---|---|---|---|---|---|
| MONTH | NUMBER | PERCENT | NUMBER | PERCENT | NUMBER | PERCENT |
| JANUARY | 64 | 30.2 | 40 | 36.4 | 24 | 23.5 |
| FEBRUARY | 64 | 30.2 | 40 | 36.4 | 24 | 23.5 |
| MARCH | 47 | 22.3 | 35 | 32.1 | 12 | 11.8 |
| APRIL | 31 | 14.7 | 28 | 25.7 | 3 | 2.9 |
| MAY | 31 | 14.7 | 28 | 25.7 | 3 | 2.9 |
| JUNE | 31 | 14.7 | 28 | 25.7 | 3 | 2.9 |
| JULY | 31 | 14.7 | 28 | 25.7 | 3 | 2.9 |
| AUGUST | 31 | 14.7 | 28 | 25.7 | 3 | 2.9 |
| SEPTEMBER | 39 | 18.5 | 33 | 30.3 | 6 | 5.9 |
| OCTOBER | 45 | 21.3 | 35 | 32.1 | 10 | 9.8 |
| NOVEMBER | 62 | 29.4 | 41 | 37.6 | 21 | 20.6 |
| DECEMBER | 67 | 31.6 | 41 | 37.3 | 26 | 25.5 |

(NOTE: Percent figures are based on the number of reporting firms for each item of data for the region concerned. This sometimes results in a different percentage for the same number of firms. This will also be the case in subsequent tables as some firms did not respond to every item.)

time, or not in business for that month.

The data for each region were considerably different; therefore Table 2 shows the results for Georgia and for each of the regions.

The Northern Region had a greater proportion of firms that were in business on a full-time basis. This was true for each month of the year. For firms that were in business on a part-time basis, the difference between the regions was not as great but the Southern Region had the largest proportion on a part-time basis for 10 of the 12 months. The Southern Region also had the greatest proportion of firms that reported they were not in business at some time. This was true for 9 of the 12 months.

One aspect of particular interest concerns the number of firms that reported they were in business on a full-time basis throughout the year. Of the 30 firms that so reported, 27 of them were in the Northern Region with only 3 in the Southern Region. The firewood business is predominantly a part-time business throughout Georgia, but this is especially so in the Southern Region.

TABLE 2B

MONTHLY PARTICIPATION IN FIREWOOD BUSINESS ON PART-TIME BASIS

NUMBER OF FIRMS ENGAGED ON PART-TIME BASIS

| | GEORGIA | | NORTHERN REGION | | SOUTHERN REGION | |
|---|---|---|---|---|---|---|
| MONTH | NUMBER | PERCENT | NUMBER | PERCENT | NUMBER | PERCENT |
| JANUARY | 132 | 62.3 | 59 | 53.6 | 73 | 71.6 |
| FEBRUARY | 125 | 59.0 | 54 | 49.1 | 71 | 69.6 |
| MARCH | 96 | 45.5 | 45 | 41.3 | 51 | 50.0 |
| APRIL | 53 | 25.1 | 26 | 23.9 | 27 | 26.5 |
| MAY | 43 | 20.4 | 20 | 18.3 | 23 | 22.5 |
| JUNE | 43 | 20.4 | 22 | 20.2 | 21 | 20.6 |
| JULY | 44 | 20.9 | 22 | 20.2 | 22 | 21.6 |
| AUGUST | 51 | 24.2 | 28 | 25.7 | 23 | 22.5 |
| SEPTEMBER | 71 | 33.6 | 38 | 34.9 | 33 | 32.4 |
| OCTOBER | 121 | 57.3 | 56 | 51.4 | 65 | 63.7 |
| NOVEMBER | 138 | 65.4 | 64 | 58.7 | 74 | 72.5 |
| DECEMBER | 140 | 66.0 | 66 | 60.6 | 74 | 72.5 |

TABLE 2C

NON-OPERATING MONTHS FOR FIREWOOD FIRMS

| | GEORGIA | | NORTHERN REGION | | SOUTHERN REGION | |
|---|---|---|---|---|---|---|
| MONTH | NUMBER OF FIRMS | PERCENT | NUMBER OF FIRMS | PERCENT | NUMBER OF FIRMS | PERCENT |
| JANUARY | 16 | 7.5 | 11 | 10.0 | 5 | 4.9 |
| FEBRUARY | 23 | 10.8 | 16 | 14.5 | 7 | 6.9 |
| MARCH | 68 | 32.2 | 29 | 26.6 | 39 | 38.2 |
| APRIL | 127 | 60.2 | 55 | 50.5 | 72 | 70.6 |
| MAY | 137 | 64.9 | 61 | 56.0 | 76 | 74.5 |
| JUNE | 137 | 64.9 | 59 | 54.1 | 78 | 76.5 |
| JULY | 136 | 64.5 | 59 | 54.1 | 77 | 75.5 |
| AUGUST | 129 | 61.1 | 53 | 48.6 | 76 | 74.5 |
| SEPTEMBER | 101 | 47.9 | 38 | 34.9 | 63 | 61.8 |
| OCTOBER | 45 | 21.3 | 18 | 16.5 | 27 | 26.5 |
| NOVEMBER | 11 | 5.2 | 4 | 3.7 | 7 | 6.9 |
| DECEMBER | 5 | 2.4 | 3 | 2.7 | 2 | 2.0 |

TABLE 3

REASONS FOR NOT BEING IN FIREWOOD BUSINESS ON A FULL-TIME BASIS THROUGHOUT THE YEAR

| REASONS | GEORGIA<br>NUMBER FIRMS | PERCENT |
|---|---|---|
| a. NO DEMAND FOR FIREWOOD IN SUMMER | 109 | 69.0 |
| b. HAVE OTHER BUSINESS INTERESTS | 68 | 43.0 |
| c. PERSONAL HEALTH PROBLEMS | 1 | 0.6 |
| d. BUSINESS NOT WELL ENOUGH ESTABLISHED | 2 | 1.3 |
| e. NEED YEAR-ROUND INDUSTRIAL CUSTOMERS | 2 | 1.3 |
| f. NOT ENOUGH MONEY TO BUY EQUIPMENT | 8 | 5.1 |
| g. SHORTAGE OF WOOD AVAILABLE TO ME | 5 | 3.2 |
| h. TOO HOT IN SUMMER | 6 | 3.8 |
| i. ADEQUATE LABOR IS NOT AVAILABLE | 1 | 0.6 |

### Reasons for Not Being in Firewood Business on a Full-Time Basis Throughout the Year

Any proposed program to expand the firewood industry must evaluate the reason why the present firms in the industry do not operate on a full-time basis throughout the year. Each firm that did not so operate was asked why they did not do so.

The responses were similar in both regions and centered predominantly around two reasons: there was little demand for firewood in the summer, and the operators had other business interests. The other business interest was frequently reported to be farming. Table 3 shows the frequency of the reasons reported.

### Sources of Wood Used by Firewood Firms

Firms in the firewood industry obtain their wood from a variety of sources with four sources being utilized most frequently. Both regions were similar in the wood sources reported. Although a specific question was not asked on the subject, respondents frequently voluntarily stated that being in the firewood business was a result of being in the tree-surgeon or tree-removal business. They sold the trees they removed. These responses were generally entered under the construction site or storm damage category of wood source. Table 4 presents the sources of wood reported by the firms.

TABLE 4

SOURCES OF WOOD REPORTED BY FIREWOOD FIRMS

| SOURCES OF WOOD | NUMBER FIRMS | PERCENT |
|---|---|---|
| CUT FROM OWN LAND | 77 | 35.6 |
| BUY ON THE STUMP FROM PRIVATE LANDOWNERS | 63 | 29.2 |
| BUY ON THE STUMP FROM STATE OR NATIONAL FORESTS | 2 | 0.9 |
| BUY IN LOG FORM DELIVERED TO MY WOODYARD | 32 | 14.8 |
| BUY BLOCK OR SPLIT WOOD DELIVERED TO MY WOODYARD | 21 | 9.7 |
| GET TREES THAT ARE CLEARED FROM CONSTRUCTION SITES OR STORM DAMAGE | 66 | 30.6 |
| FROM THINNING AND TIMBER CUTTING | 57 | 26.4 |

TABLE 5

PROBLEMS REPORTED BY FIRMS IN OBTAINING WOOD

| | GEORGIA | | NORTHERN REGION | | SOUTHERN REGION | |
|---|---|---|---|---|---|---|
| REASON | NUMBER FIRMS | PERCENT | NUMBER FIRMS | PERCENT | NUMBER FIRMS | PERCENT |
| a. FINDING ENOUGH WOOD | 27 | 52.9 | 20 | 60.6 | 7 | 38.9 |
| b. NOT ENOUGH TRUCKS | 2 | 3.9 | 1 | 3.0 | 1 | 5.6 |
| c. CANNOT CUT IN WET WEATHER | 10 | 19.6 | 6 | 18.2 | 4 | 22.2 |
| d. LACK OF LABOR | 11 | 21.6 | 5 | 15.2 | 6 | 33.3 |
| e. NOT ENOUGH EQUIPMENT | 2 | 3.9 | 2 | 6.1 | 0 | 0.0 |
| f. INCONSISTENCY OF SUPPLY | 7 | 13.7 | 6 | 18.2 | 1 | 5.6 |
| TOTAL | 51 | | 33 | | 18 | |

(NOTE: Some firms reported more than one reason.)

### Problems Reported in Obtaining Wood

A total of 51 firms reported one or more problems in obtaining an adequate supply of wood to sell as firewood. The most frequently cited reason was a general one of just not being able to find enough wood. Data are presented for each region as there was some difference between responses. These reasons are listed in Table 5.

### Distance Traveled to Obtain Wood

Firms are apparently in fairly close proximity to available sources of wood. The availability of wood is uniform throughout Georgia as the distance traveled to obtain wood was very similar for both regions. Some 74 percent of firms reported they obtained their wood within a 20 mile radius. The distances shown in Table 6 represent the maximum one-way distance that firms said they generally traveled to obtain the wood they sold as firewood.

TABLE 6

MAXIMUM ONE-WAY DISTANCE TO SOURCE OF WOOD

GEORGIA

| NUMBER OF MILES | NUMBER FIRMS | PERCENT |
|---|---|---|
| 5 OR LESS | 58 | 28.0 |
| 6 TO 10 | 47 | 22.7 |
| 11 TO 15 | 26 | 12.6 |
| 16 TO 20 | 22 | 10.6 |
| 21 TO 25 | 13 | 6.3 |
| 26 TO 30 | 18 | 8.7 |
| 31 TO 35 | 2 | 1.0 |
| 36 TO 40 | 2 | 1.0 |
| 41 TO 45 | 1 | .5 |
| 46 TO 50 | 7 | 3.4 |
| 51 TO 55 | 0 | 0.0 |
| 56 TO 60 | 3 | 1.4 |
| 61 TO 65 | 1 | .5 |
| 66 TO 70 | 1 | .5 |
| 71 TO 75 | 2 | 1.0 |
| OVER 75 | 4 | 1.9 |
| TOTAL | 207 | 100.0 |

*This is one of many woodyards established in Georgia during recent years.*

### Size of Individual Firewood Sales

The amount of firewood that is sold per order in Georgia is predominantly one-half cord. This is followed by one quarter cord and one cord. Firms were asked to state what percentage of their orders were for various amounts of firewood. Of the 213 responding firms, 86 or 40.4 percent said that over 75 percent of their orders were for one-half cord. The number of firms that reported over 75 percent of their orders were for amounts ranging from one-quarter to over 3 cords is shown in Table 7.

TABLE 7

SIZE OF INDIVIDUAL FIREWOOD SALES

FIRMS REPORTING THAT OVER 75 PERCENT
OF ORDERS WERE FOR AMOUNTS SHOWN

| SIZE OF ORDER | NUMBER OF FIRMS | PERCENT |
|---|---|---|
| ONE QUARTER CORD | 26 | 12.2 |
| ONE-HALF CORD | 86 | 40.4 |
| ONE CORD | 17 | 8.0 |
| ONE AND ONE-HALF CORD | 2 | .9 |
| TWO CORDS | 2 | .9 |
| THREE CORDS | 2 | .9 |
| OVER THREE CORDS | 6 | 2.8 |

### Sales to Residential Customers and To Others

The sale of firewood by industry firms is almost entirely to residential customers. Of the 216 responding firms, 184 stated that over 95 percent of their sales were made to homeowners. This tends to support the comment made by two firms that if more industrial or commercial customers were available, they could operate on a year-round basis. The responses for Georgia are presented in Table 8.

### Delivered Firewood and Sales at Wood Yard

In almost the same proportion that firewood was sold to homeowners rather than to other consumers, firewood is delivered to the customer rather than being sold at the wood yard. Of the 217 firms responding, 116, or 53.5 percent, reported that 96 to 100 percent of the firewood sold was delivered to the customer. It was reported by 10 percent of the firms, however, that 95 to 100 percent of their sales were made at the wood yard. The data on all firms are shown in Table 9. There was little difference in the data reported by the two regions.

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TABLE 8

DISTRIBUTION OF SALES TO HOMEOWNERS AND OTHER CONSUMERS

| PROPORTION OF WOOD SOLD TO HOMEOWNERS | GEORGIA NUMBER OF FIRMS | GEORGIA PERCENT |
|---|---|---|
| 5 PERCENT OR LESS | 1 | 0.5 |
| 6 TO 10 | 4 | 1.9 |
| 11 TO 15 | 0 | 0.0 |
| 16 TO 20 | 0 | 0.0 |
| 21 TO 25 | 1 | 0.5 |
| 26 TO 30 | 0 | 0.0 |
| 31 TO 35 | 0 | 0.0 |
| 36 TO 40 | 1 | 0.5 |
| 41 TO 45 | 0 | 0.0 |
| 46 TO 50 | 4 | 1.9 |
| 51 TO 55 | 0 | 0.0 |
| 56 TO 60 | 2 | 0.9 |
| 61 TO 65 | 0 | 0.0 |
| 66 TO 70 | 0 | 0.0 |
| 71 TO 75 | 0 | 0.0 |
| 76 TO 80 | 3 | 1.4 |
| 81 TO 85 | 0 | 0.0 |
| 86 TO 90 | 10 | 4.6 |
| 91 TO 95 | 6 | 2.8 |
| 96 TO 100 | 184 | 85.2 |
| TOTAL | 216 | 100.0 |

| PROPORTION OF WOOD SOLD TO INDUSTRIAL FIRMS, STORES, ETC | GEORGIA NUMBER OF FIRMS | GEORGIA PERCENT |
|---|---|---|
| 5 PERCENT OR LESS | 184 | 85.2 |
| 6 TO 10 | 6 | 2.8 |
| 11 TO 15 | 10 | 4.6 |
| 16 TO 20 | 0 | 0.0 |
| 21 TO 25 | 3 | 1.4 |
| 26 TO 30 | 0 | 0.0 |
| 31 TO 35 | 0 | 0.0 |
| 36 TO 40 | 0 | 0.0 |
| 41 TO 45 | 2 | 0.9 |
| 46 TO 50 | 0 | 0.0 |
| 51 TO 55 | 4 | 1.9 |
| 56 TO 60 | 0 | 0.0 |
| 61 TO 65 | 1 | 0.5 |
| 66 TO 70 | 0 | 0.0 |
| 71 TO 75 | 0 | 0.0 |
| 76 TO 80 | 1 | 0.5 |
| 81 TO 85 | 0 | 0.0 |
| 86 TO 90 | 0 | 0.0 |
| 91 TO 95 | 4 | 1.9 |
| 96 TO 100 | 1 | 0.5 |
| TOTAL | 216 | 100.0 |

TABLE 9

REPORTED SALES OF FIREWOOD AT WOOD YARD AND DELIVERED TO CUSTOMER

| | REPORTING FIRMS GEORGIA | | | REPORTING FIRMS GEORGIA | |
|---|---|---|---|---|---|
| PROPORTION OF WOOD DELIVERED TO CUSTOMER | NUMBER | PERCENT | PROPORTION OF WOOD SOLD AT WOOD YARD | NUMBER | PERCENT |
| 5 PERCENT OR LESS | 23 | 10.6 | 5 PERCENT OR LESS | 116 | 53.5 |
| 6 TO 10 | 2 | 0.9 | 6 TO 10 | 10 | 4.6 |
| 11 TO 15 | 1 | 0.5 | 11 TO 15 | 17 | 7.8 |
| 16 TO 20 | 2 | 0.9 | 16 TO 20 | 2 | 0.9 |
| 21 TO 25 | 1 | 0.5 | 21 TO 25 | 7 | 3.2 |
| 26 TO 30 | 3 | 1.4 | 26 TO 30 | 12 | 5.5 |
| 31 TO 35 | 0 | 0.0 | 31 TO 35 | 3 | 1.4 |
| 36 TO 40 | 5 | 2.3 | 36 TO 40 | 0 | 0.0 |
| 41 TO 45 | 0 | 0.0 | 41 TO 45 | 2 | 0.9 |
| 46 TO 50 | 11 | 5.1 | 46 TO 50 | 0 | 0.0 |
| 51 TO 55 | 0 | 0.0 | 51 TO 55 | 11 | 5.1 |
| 56 TO 60 | 2 | 0.9 | 56 TO 60 | 0 | 0.0 |
| 61 TO 65 | 0 | 0.0 | 61 TO 65 | 5 | 2.3 |
| 66 TO 70 | 3 | 1.4 | 66 TO 70 | 0 | 0.0 |
| 71 TO 75 | 12 | 5.5 | 71 TO 75 | 3 | 1.4 |
| 76 TO 80 | 7 | 3.2 | 76 TO 80 | 1 | 0.5 |
| 81 TO 85 | 2 | 0.9 | 81 TO 85 | 2 | 0.9 |
| 86 TO 90 | 17 | 7.8 | 86 TO 90 | 1 | 0.5 |
| 91 TO 95 | 10 | 4.6 | 91 TO 95 | 2 | 0.9 |
| 96 TO 100 | 116 | 53.5 | 96 TO 100 | 23 | 10.6 |
| TOTAL | 217 | 100.0 | TOTAL | 217 | 100.0 |

### Total Sales of Firewood

The total annual sales reported by firms were in some ways very similar between the two regions. In both regions 50 percent of the firms reported sales of 40 cords or less. In other words, the median annual sales reported was 40 cords.

The Northern Region had a greater number of firms that reported sales of 200 or more cords. This resulted in the situation where each region had a median of 40 cords per year but the Northern Region had an average of 155 cords and the Southern Region had an average of 62 cords. It will be noted in Table 10 that the Northern Region had 5 firms with sales of 1,000 or more cords while the Southern Region had only 1.

### TABLE 10

### TOTAL SALES OF FIREWOOD BY REPORTING FIRMS

NUMBER OF FIRMS REPORTING TOTAL SALES SHOWN

| TOTAL CORDS SOLD PER YEAR | GEORGIA | | NORTHERN REGION | | SOUTHERN REGION | |
|---|---|---|---|---|---|---|
| | NUMBER | PERCENT | NUMBER | PERCENT | NUMBER | PERCENT |
| 1 TO 10 | 23 | 13.8 | 11 | 12.8 | 12 | 14.8 |
| 11 TO 20 | 20 | 12.0 | 8 | 9.3 | 12 | 14.8 |
| 21 TO 30 | 23 | 13.8 | 14 | 16.3 | 9 | 11.1 |
| 31 TO 40 | 19 | 11.4 | 11 | 12.8 | 8 | 9.9 |
| 41 TO 50 | 23 | 13.8 | 10 | 11.6 | 13 | 16.0 |
| 51 TO 60 | 7 | 4.2 | 2 | 2.3 | 5 | 6.2 |
| 61 TO 70 | 5 | 3.0 | 1 | 1.2 | 4 | 4.9 |
| 71 TO 80 | 9 | 5.4 | 4 | 4.7 | 5 | 6.2 |
| 81 TO 90 | 2 | 1.2 | 1 | 1.2 | 1 | 1.2 |
| 91 TO 100 | 10 | 6.0 | 5 | 5.8 | 5 | 6.2 |
| 101 TO 125 | 6 | 3.6 | 3 | 3.5 | 3 | 3.7 |
| 126 TO 150 | 5 | 3.0 | 2 | 2.3 | 3 | 3.7 |
| 151 TO 175 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 176 TO 200 | 3 | 1.8 | 3 | 3.5 | 0 | 0.0 |
| 201 TO 250 | 1 | 0.6 | 1 | 1.2 | 0 | 0.0 |
| 251 TO 300 | 1 | 0.6 | 1 | 1.2 | 0 | 0.0 |
| 301 TO 400 | 3 | 1.8 | 3 | 3.5 | 0 | 0.0 |
| 401 TO 500 | 1 | 0.6 | 1 | 1.2 | 0 | 0.0 |
| 501 TO 750 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 751 TO 1000 | 2 | 1.2 | 2 | 2.3 | 0 | 0.0 |
| 1001 TO 1500 | 3 | 1.8 | 2 | 2.3 | 1 | 1.2 |
| over 1500 | 1 | 0.6 | 1 | 1.2 | 0 | 0.0 |
| TOTAL | 167 | 100.0 | 86 | 100.0 | 81 | 100.0 |

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## Selling Price of Firewood

It was noted earlier that prices for firewood vary considerably in Georgia, and that a stable supply of firewood at reasonable prices might encourage the use of firewood as an alternative energy source. The following data will lend substance to the claim of wide price variations.

Firms were questioned as to the price charged for .25, .5, 1, 1.5, 2 and 3 cords of firewood. Although not all firms provided a price for each quantity, sufficient responses were received to provide a data base for evaluation. It should be noted that many firms are of such nature and size that they seldom if ever sell firewood in quantities of 1.5, 2, and 3 cords.

The data on the number of firms that sell the above amounts of firewood at the prices shown are presented in Table 11. Although the data shown are for Georgia they will suffice to demonstrate the variation in price for given amounts of firewood. There was a difference in prices between the two regions but such differences will be shown later.

Even with the wide price variations some evaluation can be made of the price structure in the two regions. First, all prices obtained for a quantity of firewood

TABLE 11

PRICE OF FIREWOOD FOR VARIOUS SIZE ORDERS IN GEORGIA

NUMBER OF FIRMS THAT REPORTED INDICATED PRICES FOR LISTED AMOUNT OF FIREWOOD

| PRICE OF FIREWOOD IN DOLLARS | .25 CORD | | .5 CORD | | 1 CORD | | 1.5 CORDS | | 2 CORDS | | 3 CORDS | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | NO. | PCT. | NO. | PCT. | NO. | PCT. | NO. | PCT. | NO. | PCT. | NO. | PCT. |
| 1 TO 10 | 6 | 7.1 | 3 | 1.9 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 11 TO 20 | 37 | 44.0 | 2 | 1.2 | 1 | 1.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 21 TO 30 | 27 | 32.1 | 40 | 24.8 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 31 TO 40 | 9 | 10.7 | 65 | 40.4 | 4 | 3.8 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 41 TO 50 | 5 | 6.0 | 26 | 16.1 | 8 | 7.6 | 1 | 3.8 | 0 | 0.0 | 0 | 0.0 |
| 51 TO 60 | | | 14 | 8.7 | 11 | 10.5 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 61 TO 70 | | | 8 | 5.0 | 19 | 18.1 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| 71 TO 80 | | | 1 | 0.6 | 20 | 19.0 | 3 | 11.5 | 0 | 0.0 | 1 | 4.5 |
| 81 TO 90 | | | 1 | 0.6 | 13 | 12.4 | 3 | 11.5 | 0 | 0.0 | 0 | 0.0 |
| 91 TO 100 | | | 1 | 0.6 | 12 | 11.4 | 4 | 15.4 | 2 | 7.7 | 1 | 4.5 |
| 101 TO 110 | | | | | 4 | 3.8 | 7 | 26.9 | 1 | 3.8 | 0 | 0.0 |
| 111 TO 120 | | | | | 5 | 4.8 | 1 | 3.8 | 4 | 15.4 | 0 | 0.0 |
| 121 TO 130 | | | | | 1 | 1.0 | 1 | 3.8 | 1 | 3.8 | 0 | 0.0 |
| 131 TO 140 | | | | | 4 | 3.8 | 1 | 3.8 | 8 | 30.8 | 0 | 0.0 |
| 141 TO 150 | | | | | 3 | 2.9 | 2 | 7.7 | 4 | 15.4 | 2 | 9.1 |
| 151 TO 160 | | | | | | | 3 | 11.5 | 0 | 0.0 | 1 | 4.5 |
| 161 TO 170 | | | | | | | | | 0 | 0.0 | 0 | 0.0 |
| 171 TO 180 | | | | | | | | | 2 | 7.7 | 2 | 9.1 |
| 181 TO 190 | | | | | | | | | 0 | 0.0 | 1 | 4.5 |
| 191 TO 200 | | | | | | | | | 3 | 11.5 | 1 | 4.5 |
| 201 TO 210 | | | | | | | | | 1 | 3.8 | 7 | 31.8 |
| 211 TO 220 | | | | | | | | | | | 0 | 0.0 |
| 221 TO 230 | | | | | | | | | | | 2 | 9.1 |
| 231 TO 240 | | | | | | | | | | | 0 | 0.0 |
| 241 TO 250 | | | | | | | | | | | 0 | 0.0 |
| 251 TO 260 | | | | | | | | | | | 0 | 0.0 |
| 261 TO 270 | | | | | | | | | | | 1 | 4.5 |
| 271 TO 280 | | | | | | | | | | | 0 | 0.0 |
| 281 TO 290 | | | | | | | | | | | 0 | 0.0 |
| 291 TO 300 | | | | | | | | | | | 2 | 9.1 |
| 301 TO 310 | | | | | | | | | | | 0 | 0.0 |
| 311 TO 320 | | | | | | | | | | | 1 | 4.5 |
| TOTAL | 84 | 100.0 | 161 | 100.0 | 105 | 100.0 | 26 | 100.0 | 26 | 100.0 | 22 | 100.0 |

were added and then divided by the number of firms providing a price for that quantity. This average per firm was computed for each of the quantities under question. It will be noticed in Table 12 that the Northern Region reported a higher price for each quantity.

The averages shown in Table 12 were computed with the prices of all firms treated on an equal basis without regard to the quantity of wood actually sold. To establish a price more closely related to what most firewood was sold for it was necessary to weight prices by the quantity of wood sold at that price.

TABLE 12

AVERAGE SELLING PRICES FOR FIREWOOD

AVERAGE PRICE REPORTED FOR QUANTITY SHOWN

| QUANTITY OF FIREWOOD | GEORGIA | NORTHERN REGION | SOUTHERN REGION |
|---|---|---|---|
| .25 CORD | $ 24.10 | $ 26.80 | $ 21.00 |
| .5 CORD | 39.70 | 44.10 | 34.60 |
| 1 CORD | 81.80 | 89.30 | 69.10 |
| 1.5 CORDS | 109.00 | 110.20 | 107.50 |
| 2 CORDS | 146.20 | 150.30 | 140.50 |
| 3 CORDS | 204.10 | 207.90 | 191.00 |

The quantity of wood most often sold was one-half cord; therefore, the price that a firm charged for one-half cord was weighted by the amount of wood sold by the firm. With this procedure, the average price for one-half cord of firewood was $47.08 for Georgia, $52.38 for the Northern Region and $33.68 for the Southern Region.

*A pecan orchard becomes a massive woodyard as some wood is ricked for drying, while other wood is split and piled to await the stacking crew.*

TABLE 13

DIRECT CASH COST OF PRODUCING ONE CORD OF FIREWOOD IN GEORGIA

| DOLLAR COST TO PREPARE ONE CORD FIREWOOD | REPORTING FIRMS NUMBER | REPORTING FIRMS PERCENT |
|---|---|---|
| 1 TO 5 | 6 | 4.3 |
| 6 TO 10 | 12 | 8.5 |
| 11 TO 15 | 18 | 12.8 |
| 16 TO 20 | 14 | 9.9 |
| 21 TO 25 | 13 | 9.2 |
| 26 TO 30 | 14 | 9.9 |
| 31 TO 35 | 8 | 5.7 |
| 36 TO 40 | 12 | 8.5 |
| 41 TO 45 | 6 | 4.3 |
| 46 TO 50 | 13 | 9.2 |
| 51 TO 55 | 4 | 2.8 |
| 56 TO 60 | 9 | 6.4 |
| 61 TO 65 | 4 | 2.8 |
| 66 TO 70 | 1 | 0.7 |
| 71 TO 75 | 3 | 2.1 |
| 76 TO 80 | 2 | 1.4 |
| 81 TO 85 | 1 | 0.7 |
| 86 TO 90 | 1 | 0.7 |
| TOTAL | 141 | 100.0 |

### Price Changes

One final aspect of prices was investigated during the study. Firms were asked if their pricing structure included lower prices during the non-heating season. They were also questioned on changes in price between 1979 and 1980. This inflation price change did not apply to 44 firms that were in business for the first time in 1980.

Discounts for the non-heating season were reported by only 8 firms with one firm offering a 5 percent discount, 6 firms a 10 percent discount, and 1 firm a 20 percent discount.

Price increases between 1979 and 1980 were reported by 53 firms. Sixty-six percent of the increases were from 10 to 15 percent whereas 28 percent of the increases were from 20 to 30 percent.

### Cost of Firewood To Firm

Firms were asked to provide information on the direct cash cost of preparing one cord of wood for sale as firewood. Costs to be included were limited to the direct expenses, such as cost of trees, labor, fuel, etc. The cost of equipment, trucks, taxes, and other indirect costs were not to be included.

There was a considerable range of costs as can be seen in Table 13. Both regions reported a similar range of costs, the Northern Region had the higher average of $39.75 per cord. The average for the Southern Region was $26.06 and for Georgia, $33.10.

### A Comparison of Times When Firewood is Cut and Sold

It was noted earlier that most firms operate on a part-time basis and generally in the period from October to February. In the same vein all firms were asked to provide information on how many cords of firewood were cut and prepared each month and how many cords of firewood were sold each month. The data supplied from both regions were quite similar.

As could be expected, the sales of firewood in the period from October to February were higher than the number of cords cut. To permit this drain, it was, of course, necessary that the number of cords cut be greater than the number sold for the period March to September.

The data in Table 14 outlines when wood was cut and when it was sold. It should be noted that the number of cords cut and sold do not represent the total from all firms. Many firms did not maintain records of this nature or chose not to provide this information. The information was provided by 149 firms.

TABLE 14

MONTHLY DISTRIBUTION OF TIMES WHEN FIREWOOD IS CUT AND WHEN IT IS SOLD

GEORGIA

| | CORDS CUT | | CORDS SOLD | |
|---|---|---|---|---|
| MONTH | NUMBER | PERCENT | NUMBER | PERCENT |
| JANUARY | 1,037 | 7.9 | 1,920 | 15.4 |
| FEBRUARY | 947 | 7.2 | 1,440 | 11.4 |
| MARCH | 830 | 6.3 | 565 | 4.5 |
| APRIL | 753 | 5.7 | 182 | 1.5 |
| MAY | 886 | 6.8 | 157 | 1.3 |
| JUNE | 872 | 6.7 | 163 | 1.3 |
| JULY | 763 | 5.8 | 168 | 1.3 |
| AUGUST | 930 | 7.1 | 204 | 1.6 |
| SEPTEMBER | 994 | 7.6 | 529 | 4.2 |
| OCTOBER | 1,684 | 12.8 | 1,686 | 13.5 |
| NOVEMBER | 1,914 | 14.6 | 2,743 | 22.0 |
| DECEMBER | 1,496 | 11.4 | 2,707 | 21.7 |
| TOTAL | 13,106 | 100.0 | 12,464 | 100.0 |

### Number of Employees in Firewood Firms

It was noted earlier that the typical firm had only one or two employees. It might be anticipated that the number of employees would be closely related to the number of cords of firewood that were sold. This did not prove to be the case. As can be seen in Table 15, 75 percent of the firms had only 1 or 2 employees and only 6 percent had more than 4 employees.

Table 16 provides additional information on the absence of a relationship between the amount of firewood sold and the number of employees. The sales of firms with 1, 2, or 3 employees all varied from less than 25 to 1,000 or more. The data provided from firms in both regions were similar and in each region there was no apparent relationship between number of employees and total sales.

TABLE 15

AVERAGE NUMBER OF EMPLOYEES IN FIREWOOD FIRMS

GEORGIA

| | REPORTING FIRMS | | | REPORTING FIRMS | |
|---|---|---|---|---|---|
| NUMBER OF EMPLOYEES | NUMBER | PERCENT | NUMBER OF EMPLOYEES | NUMBER | PERCENT |
| 1 | 74 | 36.3 | 13 | 0 | 0.0 |
| 2 | 78 | 38.2 | 14 | 0 | 0.0 |
| 3 | 26 | 12.7 | 15 | 0 | 0.0 |
| 4 | 13 | 6.4 | 16 | 0 | 0.0 |
| 5 | 5 | 2.5 | 17 | 0 | 0.0 |
| 6 | 3 | 1.5 | 18 | 0 | 0.0 |
| 7 | 1 | 0.5 | 19 | 0 | 0.0 |
| 8 | 1 | 0.5 | 20 | 0 | 0.0 |
| 9 | 0 | 0.0 | 21 TO 25 | 0 | 0.0 |
| 10 | 0 | 0.0 | 26 TO 30 | 1 | 0.5 |
| 11 | 1 | 0.5 | | | |
| 12 | 1 | 0.5 | | | |
| | | | TOTAL | 204 | 100.0 |

## TABLE 16

### REPORTED NUMBER OF EMPLOYEES IN FIREWOOD FIRMS IN GEORGIA

NUMBER OF FIRMS THAT REPORTED NUMBER OF EMPLOYEES SHOWN

| VOLUME OF SALES IN CORDS | NUMBER OF EMPLOYEES |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11-12 | 13-14 | 15-17 | 18-20 | 21-24 | 25-30 |
| 1 TO 25 | 17 | 26 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 26 TO 50 | 23 | 17 | 10 | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 51 TO 75 | 8 | 5 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 76 TO 100 | 8 | 5 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 101 TO 125 | 0 | 3 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 126 TO 150 | 1 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 151 TO 175 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 176 TO 200 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 201 TO 250 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 251 TO 300 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 301 TO 350 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 351 TO 400 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 401 TO 450 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 451 TO 500 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 501 TO 1000 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| OVER 1000 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

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## TABLE 17

### CORDS OF FIREWOOD THAT WOULD HAVE TO BE SOLD FOR FIRMS TO REMAIN IN BUSINESS ON YEAR-ROUND BASIS

| REQUIRED VOLUME OF SALES | GEORGIA REPORTING FIRMS |  |
|---|---|---|
|  | NUMBER | PERCENT |
| 1 TO 25 CORDS | 1 | 0.9 |
| 26 TO 50 | 3 | 2.7 |
| 51 TO 75 | 1 | 0.9 |
| 76 TO 100 | 6 | 5.5 |
| 101 TO 125 | 4 | 3.6 |
| 126 TO 150 | 3 | 2.7 |
| 151 TO 175 | 1 | 0.9 |
| 176 TO 200 | 12 | 10.9 |
| 201 TO 250 | 7 | 6.4 |
| 251 TO 300 | 15 | 13.6 |
| 301 TO 350 | 3 | 2.7 |
| 351 TO 400 | 10 | 9.1 |
| 401 TO 450 | 2 | 1.8 |
| 451 TO 500 | 10 | 9.1 |
| 501 TO 600 | 4 | 3.6 |
| 601 TO 700 | 2 | 1.8 |
| 701 TO 800 | 1 | 0.9 |
| 801 TO 900 | 1 | 0.9 |
| 901 TO 1000 | 8 | 7.3 |
| 1001 TO 1250 | 2 | 1.8 |
| 1251 TO 1500 | 1 | 0.9 |
| 1501 TO 1750 | 0 | 0.0 |
| 1751 TO 2000 | 2 | 1.8 |
| 2001 TO 2500 | 1 | 0.9 |
| 2501 TO 3000 | 0 | 0.0 |
| OVER 3000 | 10 | 9.1 |
| TOTAL | 110 | 100.0 |

### Sales Required to be in Business Full-Time

The firewood industry in Georgia is predominantly a part-time business with operators depending upon another business interest as a primary occupation. If a program to expand the industry and therefore provide a more stable supply of firewood is to be developed, some information is essential on the volume of sales that would be required to encourage an individual to enter the industry on a full-time basis.

Firms that were not operating on a full-time basis throughout the year were asked to provide information on the number of cords they would have to sell to remain in the industry on a full-time basis.

The replies from the 100 firms that responded were similar from both regions but the required volume of sales varied widely. Table 17 presents the number of firms and the annual sales volume they would need to remain in business full-time.

One area in which the two regions reported different data was in the average sales per firm that would be required. In the Northern Region the average per firm of required sales was 1,334 cords per year. In the Southern Region, the average was only 578 cords per year. The average for Georgia was 945 cords.

TABLE 18

LENGTH OF DRYING TIME FOR FIREWOOD BEFORE SALE

| | REPORTING FIRMS | | | | | |
|---|---|---|---|---|---|---|
| NUMBER OF MONTHS DRYING TIME | GEORGIA | | NORTHERN REGION | | SOUTHERN REGION | |
| | NUMBER | PERCENT | NUMBER | PERCENT | NUMBER | PERCENT |
| 0 | 76 | 36.0 | 29 | 26.4 | 47 | 46.5 |
| 1 | 28 | 13.3 | 14 | 12.7 | 14 | 13.9 |
| 2 | 29 | 13.7 | 15 | 13.6 | 14 | 13.9 |
| 3 | 26 | 12.3 | 17 | 15.5 | 9 | 8.9 |
| 4 | 14 | 6.6 | 11 | 10.0 | 3 | 3.0 |
| 5 | 2 | 0.9 | 1 | 0.9 | 1 | 1.0 |
| 6 | 26 | 12.3 | 20 | 18.2 | 6 | 5.9 |
| 7 | 1 | 0.5 | 1 | 0.9 | 0 | 0.0 |
| 8 | 5 | 2.4 | 0 | 0.0 | 5 | 5.0 |
| 9 | 3 | 1.4 | 1 | 0.9 | 2 | 2.0 |
| 10 | 1 | 0.5 | 1 | 0.9 | 0 | 0.0 |
| TOTAL | 211 | 100.0 | 110 | 100.0 | 101 | 100.0 |

### New Employees Required to Meet Annual Sales Volume Necessary to Stay in Business Full-Time

If firms could be encouraged to stay in business full-time and achieve the required sales volume noted above, it should be anticipated that significant new employment opportunities would be created. In addition to the required sales volume, firms were asked to estimate the number of employees they would require to meet the new sales volume.

Despite the increase from the present average sales in Georgia of 110 cords to the required average annual sales of 945 cords, the increase in the number of employees was very small. For Georgia the increase in number of employees was an average of 1.17 employee per firm. There was a difference between the Northern and Southern regions in the average number of new employees required. In the Northern Region the average was 1.5 new employees per firm while in the Southern Region the average was only .85 employees.

### Drying Period for Firewood

There was a discernible difference between the two regions in the length of time that firewood was permitted to dry before sale. As can be seen in Table 18, firewood was given a generally longer drying period in the Northern Region.

It can also be observed that 35 percent of the firms did not allow any time for the wood to dry. It should be noted, however, that this was not necessarily an attempt to sell an inferior product. Frequently respondents explained that the procedure of the firm was to cut wood on an "as ordered" basis only, thus eliminating a storage cost and drying time.

The average drying time in the Northern Region was 2.64 months while in the Southern Region it was 1.78 months.

### Equipment Requirements

Participation as a firm in the firewood industry requires a substantial capital investment in equipment even at very low levels of annual sales. Even at minimum sales levels there is generally a requirement for a chain saw and a truck. As sales increase, there is a point where additional units such as splitters and loaders become a necessity.

In this study equipment investment was compared for two groups. One group had sales of 200 cords or less while the second group reported sales of over 200 cords.

As can be seen in Table 19, the equipment investment for a firm with sales of over 200 cords was 14 times as great as for a firm with sales of 200 cords or less.

The equipment investment for the two regions was very similar as to the items of equipment, but firms in the Northern Region reported somewhat higher costs for equipment. The average investment for firms selling 200 cords or less was $8,040 for the Northern Region and $5,082 for the Southern Region.

*A woodyard owner operates an automatic splitter, one of the great labor saving machines that has been invented in recent years to make volume production possible.*

---

TABLE 19

EQUIPMENT INVESTMENT OF FIREWOOD FIRMS IN GEORGIA

TOTAL ANNUAL SALES OF FIRMS

| | 200 CORDS OR LESS | | | OVER 200 CORDS | | |
|---|---|---|---|---|---|---|
| TYPE OF EQUIPMENT | NUMBER OF FIRMS WITH EQUIPMENT | TOTAL PIECES OF EQUIPMENT | AVERAGE COST OF EQUIPMENT | NUMBER OF FIRMS WITH EQUIPMENT | TOTAL PIECES OF EQUIPMENT | AVERAGE COST OF EQUIPMENT |
| CHAIN SAWS | 119 | 205 | $ 336 | 9 | 19 | $ 329 |
| TRUCKS | 107 | 130 | 3,535 | 11 | 25 | 6,856 |
| TRACTORS | 11 | 11 | 4,277 | 0 | 0 | 0 |
| SKIDDER AND GRAPPLE | 1 | 1 | 2,500 | 2 | 6 | 47,000 |
| TRAILERS | 6 | 10 | 3,110 | [illegible] | 0 | 0 |
| DUMP TRUCKS | 6 | 8 | 4,875 | 0 | 0 | 0 |
| SPLITTERS | 36 | 37 | 1,926 | 7 | 7 | 23,443 |
| BANDING MACHINES | 0 | 0 | 0 | 2 | 2 | 52,500 |
| BOOM LOADERS | 7 | 7 | 9,714 | 4 | 6 | 32,333 |

| | 200 CORDS OR LESS | OVER 200 CORDS | FOR ALL FIRMS |
|---|---|---|---|
| TOTAL NUMBER OF FIRMS IN GROUP | 120 | 10 | 130 |
| TOTAL EQUIPMENT INVESTMENT FOR GROUP | $787,318 | $922,750 | $1,710,068 |
| AVERAGE INVESTMENT PER FIRM IN GROUP | 6,561 | 92,275 | 13,154 |
| AVERAGE CORDS SOLD PER GROUP | 49 | 891 | 110 |
| MEDIAN CORDS SOLD PER GROUP | 40 | 668 | 40 |

Program to Improve Industry

Firewood dealers were asked to give their opinions on factors that might be included in a government program to promote the use of firewood and assist the firms in the firewood industry.

Two factors were by far the most frequently cited. First, there should be a low interest loan program that would permit dealers to purchase sufficient equipment to operate on a larger scale. Next, action should be taken to insure a ready supply of wood. This could be done by making wood available from federal or state forests or by locating and encouraging private landowners to sell wood to firewood dealers.

It should also be noted that a significant number of dealers were of the opinion that government should not become involved in the firewood business.

The following recommendations were also noted:

a. Educate the public on the use of firewood as an energy source.
b. Provide income tax credit for purchase of firewood stoves and firewood.
c. Government purchase firewood and distribute to needy.
d. Encourage industrial use of firewood by an education program and by special tax incentives.
e. Provide training for firewood dealers on new equipment and business methods.
f. Help provide labor through a "CETA" type program.
g. Require dealers to be licensed.
h. Promote an association of firewood dealers.
i. Provide local reports on available sources of wood.
j. Reduce income tax on income from selling firewood.
k. Provide cost-sharing for private landowners who will plant and manage wood-lots for firewood use.
l. Provide tax incentives for firewood firms that create "new" job openings for unskilled unemployed labor.
m. Prohibit the burning of wood waste when land is cleared.
n. Establish "Wood Markets" similar to "Farmers' Markets".

Industry Trends

The apparent growth in the use of firewood for household heating has set the stage for a change in the scope of operations for firms in the industry. The typical chain saw and pick-up truck level of operation will continue to serve most local areas throughout Georgia but there is evidence that large consumer markets will be served by a new type of firm.

The increasing demand for firewood has attracted technology to the problem of supplying large quantities of firewood through more efficient and less costly operations. Machines have now reached the market that introduce a considerable level of automation to the cutting, splitting and loading of firewood. Where automation is not possible, the task of moving large logs and preparing them for cutting and splitting has been made easier by heavy special duty equipment.

It is now possible to replace the firm that cuts and sells perhaps one cord of wood a day with a new organization that can produce 20 cords of split firewood in an 8 hour day. The one-half cord pick-up truck can be replaced by trucks that easily handle 10 cords.

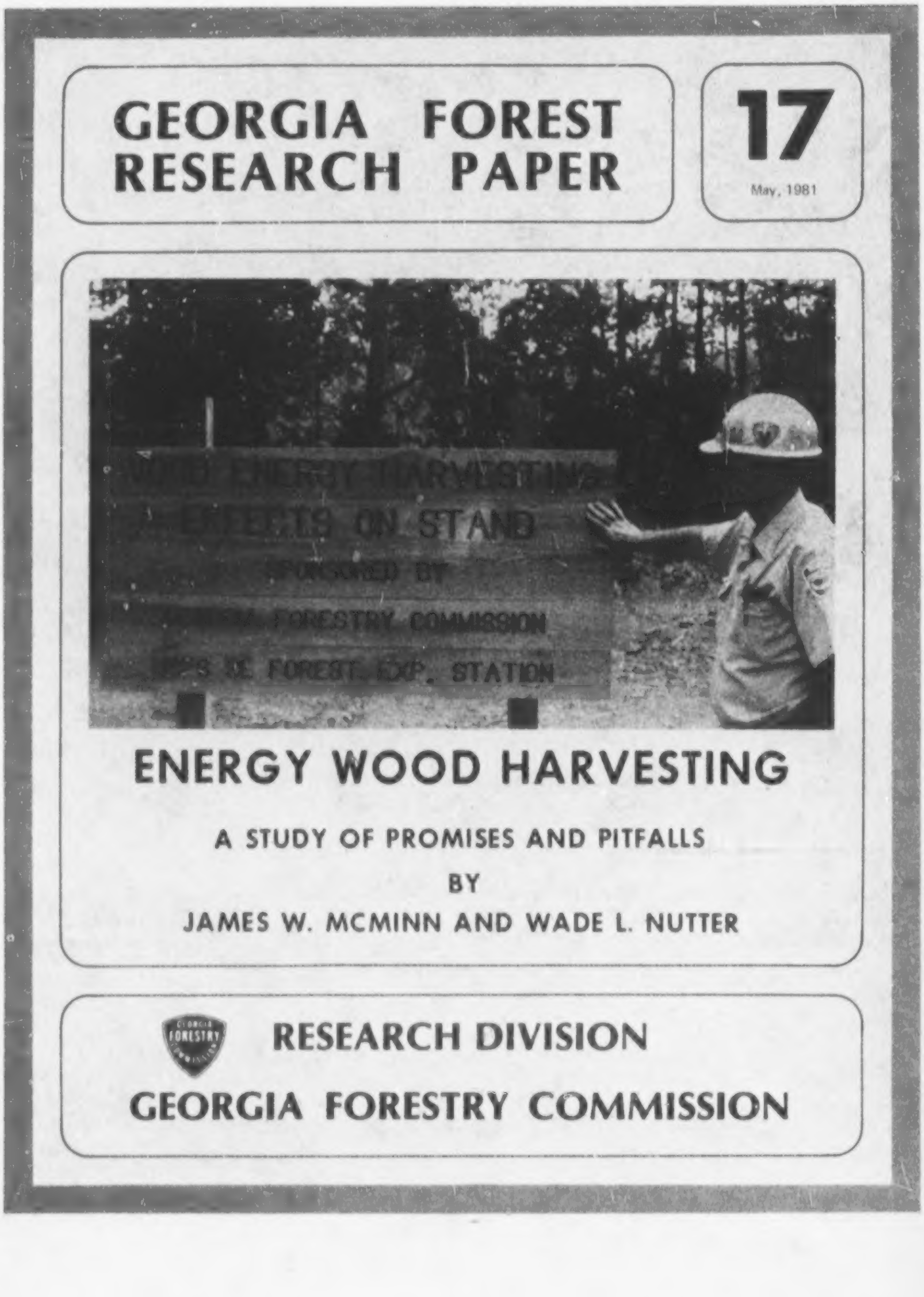
Three such firewood firms were started in North Georgia in 1980. These firms have invested in new equipment that can be operated by from 1 to 3 men and can produce 20-22 cords of firewood in an 8 hour day. In such an operation, one crew of four men cuts trees, loads them on trailers, and carries the logs to the wood yard. A yard crew then cuts the logs into lengths that can be accommodated by the saw and splitting machine. These lengths can vary from 8 to 40 feet. The machine crew of 1 to 3 men cuts and splits the firewood which then goes by conveyor belt either into a waiting truck or to a wood pile where it is subsequently loaded by use of lift trucks.

Other features of the machinery include the ability to band bundles of wood, wrap them in plastic, or fasten them to large pallets.

It is likely that the cost efficiency of such firms will permit them to transport firewood in large quantities for distances that have, until now, been prohibitive. Firms will be able to be located near the source of wood and still serve large consumer areas such as Atlanta.

These large volume firms will have the option of producing the firewood and selling it through their own retail outlets, or they can concentrate on selling it at wholesale to firms that will sell it at retail.

*A landowner and a forester survey a stand to determine trees that should be cut for fuelwood purposes. Georgia has an abundance of hardwood acreage such as this that could be harvested for firewood.*



GEORGIA FOREST RESEARCH PAPER

17

May, 1981

# ENERGY WOOD HARVESTING

A STUDY OF PROMISES AND PITFALLS

BY

JAMES W. MCMINN AND WADE L. NUTTER

RESEARCH DIVISION

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# ACKNOWLEDGMENT

The authors gratefully acknowledge the financial support and in kind contributions by the Georgia Forestry Commission. Special thanks are due Winston West, Forest Manager, Dawson Forest, David McClain, Forester, Division of Research and the other dedicated employees of the Commission, without whom this research would not be possible.

A number of factors must be considered in choosing an intensity and season of harvest. Total nutrient removal by harvesting, erosion, and leaching is obviously related to harvest intensity. In addition, since hardwood foliage contains a higher nutrient concentration than other tree components, harvesting during the summer, when the trees are in full foliage, may remove more nutrients than a winter harvest. This is not the only consideration, however. For some species, evidence exists that stump sprouting is more prolific following winter harvests than after summer harvests (1). Summer harvesting, therefore, may result in less sprouting and a higher ratio of seedling to sprout reproduction. Most seedlings will likely be conifers and light-seeded, intolerant hardwoods with a higher commercial value than the heavy seeded hardwoods that currently dominate (3). In other words, intensive summer harvesting will theoretically have the greatest positive impact on commercial species composition and stand structure. The ultimate objectives of the research are to estimate the positive and negative influences and quantify the tradeoffs between them.

## PROCEDURES

The research is being conducted on the Dawson Forest, Dawson County, in the Upper Piedmont of Georgia, which is managed by the Georgia Forestry Commission. Commission personnel conducted the harvesting operations during the winter of 1979-80 and the summer of 1980. A typical whole-tree system, consisting of a feller-buncher, grapple skidders, and an 18-inch chipper, was employed (figure 2).

The sites had at one time been farmed, then abandoned and allowed to revert to forest. The resulting timber stands have been high-graded until no merchantable timber remains or the merchantable volume is too low for traditional logging. Basal area averages about 100 square feet per acre, of which about 65 percent is hard hardwood, 10 percent soft hardwood, and 25 percent pine. Hard hardwood diameters range from 1 to 20 inches, soft hardwood from 1 to 16 inches, and pine from 1 to 14 inches. The soil type is Fannin fine sandy loam with inclusions of Tallapoosa fine sandy loam.

Each combination of season and harvest intensity, as well as a control, is replicated three times on 1-acre logging plots with detailed measurements and sampling confined to the interior ½-acre.

Site impact is being characterized via estimates of logging disturbance, total site nutrient pools, and nutrient removals.

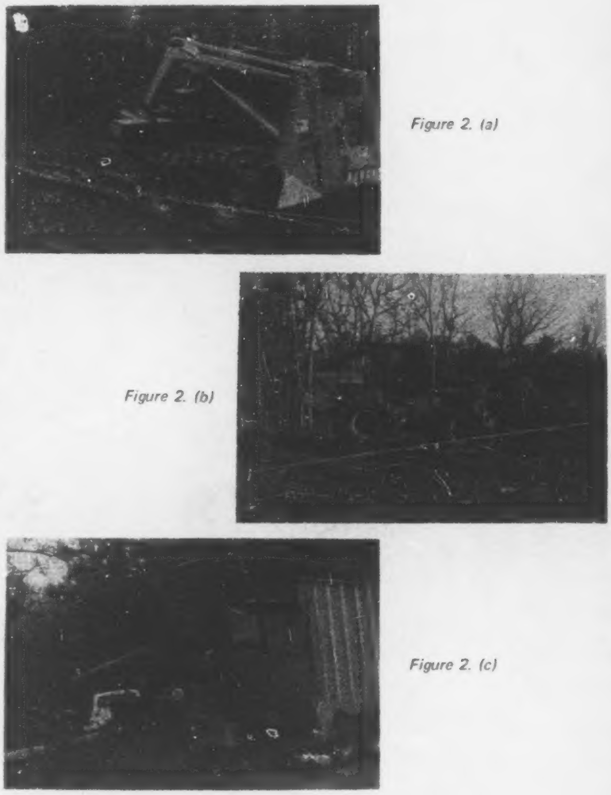

Figure 2. (a)

Figure 2. (b)

Figure 2. (c)

*Figure 2. Whole-tree harvesting system consisting of (a) feller-buncher, (b) grapple-skidder, and (c) chipper.*

Logging disturbance is estimated on the basis of a 180-point systematic grid within each plot. Each point is classed as (1) undisturbed, (2) mineral soil exposed but not dislocated, or (3) soil dislocated.

Amounts of nutrients in aboveground biomass, in the forest floor, and in the soil are estimated. Samples of the forest floor and soil are collected on a systematic grid. Composite samples of aboveground biomass were obtained by chipping all harvested material and taking periodic grab samples as the chips were blown into a van, which was then weighed. All nutrient samples are being analyzed for nitrogen, phosphorous, potassium, calcium, magnesium, aluminum, iron, manganese, and zinc.

### Vegetation

Influences on forest vegetation will be gauged by estimating (1) the degree of competition to seedlings by residual stems and sprouts, (2) pine seedling establishment, (3) species composition and structure of the succeeding stands, and (4) biomass regrowth.

Differences in shade competition resulting from the two harvest intensities are being estimated by measuring light intensities in the photosynthetically active range of the solar spectrum. Instantaneous readings are taken on cloudless days within 1 hour of solar noon at 40

# ENERGY WOOD HARVESTING

## A STUDY OF PROMISES AND PITFALLS

BY

JAMES W. MCMINN AND WADE L. NUTTER

## INTRODUCTION

The oil embargo of 1973-74 and continuing instabilities in the Middle East have focused attention on alternate energy sources. The use of woody biomass as an alternate energy source presents potential opportunities and problems for the owners and managers of forestland. Among the potential opportunities is the promise of markets for previously unmerchantable material and a mechanism for increasing production of the quality timber required for many traditional wood products (2). Among the potential problems are nutrient removal, leaching, and erosion that could reduce the productive capacity of the forestland--an aspect of more intensive harvesting that is of international concern (5). This paper describes research in progress to define more precisely the potential benefits and impacts associated with intensive harvesting of wood for energy.

## RATIONALE AND OBJECTIVES

Investigations described here are confined to the mixtures of low-quality hardwood and pine that typify much of the Upper Piedmont (figure 1). Two intensities of whole-tree harvesting were chosen. The most drastic treatment was to remove all woody biomass down to and including stems of approximately 1-inch in diameter at breast height. The other harvest intensity was to remove all stems with a breast height diameter of 4 inches and larger. Several operational and biological factors were considered in arriving at the two intensities in combination with the two seasons of harvest.

From an operational standpoint, we began with the premise that no management whatever will take place in the type of stand studied unless the material can be economically removed for fuel. Most of the material is not suitable for any other wood product, and expected return on investment is too low to justify the cost of clearing such sites and establishing more valuable species. The 4-inch diameter was used because it is the approximate lower limit for commercial harvest of fuelwood: no larger diameter limit is appropriate because no alternate product is possible. The 1-inch limit cut was included because, even though the smaller classes will not pay their way, removal of the small material may be justified by long-term benefits to the new stand. More than a generation of experience has demonstrated that on most nonindustrial private forest acreage no management activities will take place after logging. Even after the most intensive clearcuts to date, cull stems and small residuals of such poor quality that management often is not feasible dominate the new stand (4). If a fuelwood harvest will pay for removal of all the woody biomass, the species composition and structure of the new stand may support future harvests for a combination of fuel and other wood products. Thus, an intensive whole-tree harvest--the only likely treatment on much acreage--may, by itself, initiate a cycle of commercial production.

*Figure 1. Low-quality hardwood-pine mixture in the Upper Piedmont*

groundline sample points along the diagonal of each plot.

Initial pine seedling establishment will be estimated from milacre inventories along the same systematic grids utilized to estimate soil disturbance.

Species composition, stand structure, and biomass regrowth will require at least 5 years to estimate. The first two variables will be obtained from complete inventories of the ½-acre measurement plots and biomass regrowth from area subsamples within those plots.

## PRELIMINARY RESULTS AND DISCUSSION

Although definitive conclusions cannot be made yet, some preliminary results are available. Total biomass removed under the most intensive harvest ranged from 67 to 83 green tons per acre. Moisture content of biomass ranged from 61 to 72 percent of ovendry weight. It is estimated that harvest to the 4-inch limit will yield approximately 15 percent less tonnage than harvest to the 1-inch limit. As the diameter limit is decreased, however, the number of stems handled increases substantially. Of the approximately 980 stems per acre, almost 60 percent are from 0.5 to 2.4 inches in diameter, but these stems account for only about 8 percent of the total basal area per acre (Table 1). These data point up a need for reliable information on whole-tree harvesting costs for small stems.

Table 1. Relative distribution of number of stems and basal area by diameter. (1980 stems per acre, 103 square feet of basal area per acre).

| Diameter range | Trait | |
|---|---|---|
| | Stems/A | Basal Area/A |
| inches | percent | |
| 0.5 - 2.4 | 58.6 | 8.4 |
| 2.5 - 4.4 | 20.9 | 17.4 |
| 4.5 - 6.4 | 9.9 | 18.3 |
| 6.5 - 8.4 | 5.1 | 16.7 |
| 8.5 - 10.4 | 3.5 | 18.6 |
| 10.5 - 12.4 | 1.2 | 9.1 |
| 12.5 - 14.4 | 0.5 | 5.5 |
| 14.5 - 16.4 | 0.2 | 3.6 |
| 16.5+ | 0.2 | 2.3 |

Table 2. Area of exposed mineral soil by intensity and season of whole-tree harvesting.

| Season | Harvest Limit | |
|---|---|---|
| | 1 inch | 4 inches |
| | Percent | |
| Winter | 71 | 35 |
| Summer | 61 | 30 |

Light measurements to date indicate that the two intensities of harvest led to substantial differences in competition from residual stands. The 4-inch limit plots receive less than 70 percent as much photosynthetically active isolation as the 1-inch limit plots during the summer (figure 3). This result documents the general consensus among foresters in the region that commercially clearcut areas need further treatment if intolerant species are desired as a major component of subsequent stands. The least intensive harvest in this study removed more material than would be removed in the typical commercial clearcut.

The area of soil disturbed by logging was logical and consistent both by season and intensity of harvest (Table 2). During both seasons the 4-inch-limit harvest disturbed half as much area as the 1-inch. Also, both intensities disturbed only 86 percent as much area during the summer as during the winter when the soil was moist. No conclusion can be drawn at present about the relative influences of soil disturbance under the two harvest intensities. Our ultimate goal is to define tradeoffs in terms of commercially utilizable production. The earliest indicator will be initial pine seedling establishment. Pines are singled out for special attention here because of their relative worth compared to hardwoods on the upland sites studied. General observations indicate that pine seedlings are becoming established in the most intensively harvested areas in a much greater proportion than their representation in the initial stands (figure 4).

*Figure 3. (a)*

*Figure 3. (b)*

*Figure 3. Residual stands following harvests down to (a) 4-inch and (b) 1-inch diameter limits.*

Preliminary estimates of macronutrient removal are presented in Table 3. Average nutrient removal per acre for all harvested plots was 300 pounds of nitrogen, 15.6 pounds of phosphorous, 110 pounds of potassium, and 500 pounds of calcium. Preliminary statistical analyses indicate that removal of biomass and of nitrogen, phosphorous, and calcium were significantly influenced by season of harvest, but not by intensity of harvest. Even conclusions about short-term nutrient removal cannot be made until forest floor and soil analyses are completed, and it will take many years to determine the more important question of impact on long-term site productivity.

## SUMMARY

This paper reports preliminary results from a whole-tree harvesting study in mixed stands of hardwood and pine in the Upper Piedmont. Treatment variables are season of harvest in combination with diameter-limit cutting down to 1 inch and 4 inches. Biomass yields ranged from 67 to 83 green tons per acre, and biomass moisture content ranged from 61 to 72 percent. Photosynthetically active solar insolation is only 70 percent as intense under the residual 4-inch-limit stands as under the 1-inch-limit stands. Soil disturbance under the 4-inch-limit was half that under the more intensive harvest and only 86 percent as much area was disturbed in the summer as during the winter. Nutrient removal, averaged for all treatments, was approximately 300, 15.6, 110, and 500 pounds per acre of nitrogen, phosphorous, potassium, and calcium, respectively. The study is continuing to determine impact on site productivity and forest management options.

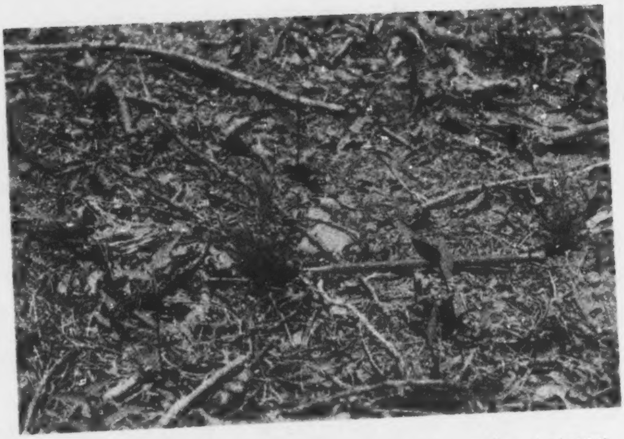

*Figure 4. Pine seedlings established within 6 months of the most intensive harvest.*

Table 3. Preliminary estimates of the mass of nutrients removed in whole-tree chips by intensity and season of harvest.

| Diameter limit and season of harvest | Nutrient N | Nutrient P | Nutrient K | Nutrient Ca |
|---|---|---|---|---|
| | pounds/acre | | | |
| 1 inch Summer | 340 | 16.8 | 113 | 546 |
| 1 inch Winter | 282 | 14.9 | 108 | 493 |
| 4 inches Summer | 339 | 17.2 | 117 | 569 |
| 4 inches Winter | 238 | 13.5 | 101 | 448 |
| MEAN | 300 | 15.6 | 110 | 500 |

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# GEORGIA FOREST RESEARCH PAPER

## 21

AUGUST, 1981

## TBCP--A COMPUTER PROGRAM THAT ESTIMATES:

**TOTAL TREE CHIPS**

**SAW LOGS**

**PULPWOOD**

**FIREWOOD**

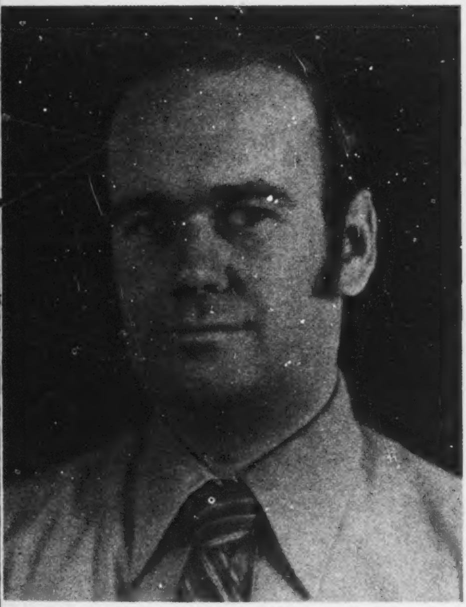
BY

ALEXANDER CLARK III AND RICHARD C. FIELD

RESEARCH DIVISION

GEORGIA FORESTRY COMMISSION

# AUTHORS



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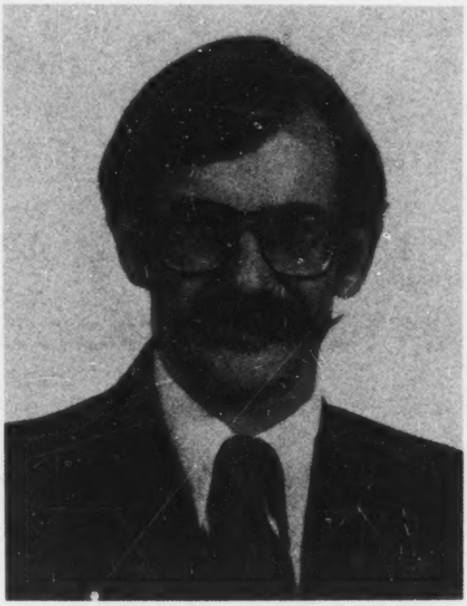

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# TBCP--A COMPUTER PROGRAM THAT ESTIMATES TOTAL TREE CHIPS, SAW LOGS, PULPWOOD, AND FIREWOOD FROM CRUISE SUMMARY DATA.

BY

ALEXANDER CLARK, III AND RICHARD C. FIELD

# INTRODUCTION

It is no longer sufficient for foresters to tell a landowner only the board foot volume or number of cords in a tract of timber that is considered for sale. Southern pines are now marketed for veneer, saw logs, and pulpwood by weight rather than stick scaled to determine board foot and cord volume. Total trees can now be marketed for fuel chips and poor quality hardwoods sold for firewood. To assist landowners in making forest management decisions and to improve utilization practices, foresters need an easy-to-use procedure for simultaneously estimating the weight and volume of total trees and their forest products. The Total Biomass Cruise Program (TBCP) meets this need[1].

TBCP is an efficient, easy to use computer program that determines the weights and volumes of total trees, saw logs, pulpwood, and firewood given standard tree cruise data. The program provides per acre and per tract estimates of total tree and tree component biomass yields for forest-grown trees 1-inch d.b.h. and larger. These estimates may be reported in tons, cords, or cunits (100 cubic feet of wood excluding bark) and saw log volumes in board feet using either the Doyle, Scribner, or International ¼-inch board foot rules.

The program is designed for use by foresters with little or no previous computer experience. To access TBCP, the user needs a computer terminal and a telephone to connect the terminal with the computer on which TBCP is stored (Figure 1). The TBCP program will instruct the user on how to answer various questions about the cruise and to input the tree data in an interactive mode. A general users manual is currently available in draft form (1).

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[1] TBCP was developed by the Utilization of Southern Timber and the Mensurational Concepts for Forest Management Decisions Research Work Units, USDA Forest Service, Southeastern Forest Experiment Station, in cooperation with the Georgia Forestry Commission.

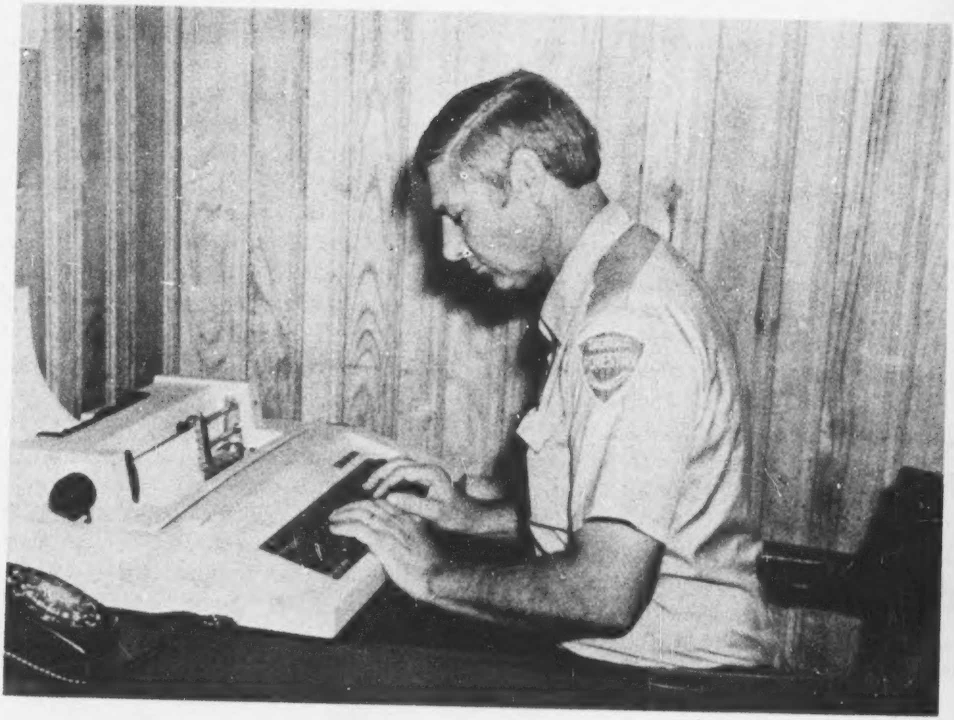

Figure 1--Georgia Forestry Commission service forester entering cruise summary data into TBCP using a computer terminal.

## PROGRAM DESIGN

TBCP is a versatile program permitting foresters to collect tree cruise data using their normal cruise procedures and estimate stand biomass and forest product yields. The following standard cruise methods are accepted by the program: (1) fixed area plots--for any specified plot size, (2) point sample--using a prism with any specified prism factor, (3) strip cruise--given the width and total length of the strip or percent of tract cruised and size of tract, and (4) 100 percent mark tally. The cruise data are entered by three species groups: pine (natural or plantation southern pine or white pine), hard hardwoods and soft hardwoods. The program will also accept data by commercially important individual species and will provide reports accordingly.

The user enters the cruise data by one or two inch d.b.h. classes and by 5- or 10-foot height intervals or by half-logs. The program will handle cruise data for forest-grown trees 1 to 40 inches d.b.h. and 5 to 140 feet in height or containing up to six 16-foot saw logs. Trees are separated into three tree size classifications for input, analysis, and output:

Sapling trees--between 1.0 and 5.0 inches d.b.h.
Pulpwood trees--between 5.0 and 9.0 inches for pine and between 5.0 and 11.0 inches d.b.h. for hardwoods.
Sawtimber trees--above 9.0 inches d.b.h. for pine and above 11.0 inches d.b.h. for hardwoods.

This permits the forester to choose from a variety of tree d.b.h. and height combinations to measure while making a cruise. Any of the following tree dimension combinations may be used.

In a single analysis the same dimensions must be used for soft hardwood and hard hardwood but different dimensions may be specified for the pine.

| Tree classification | Tree dimensions measured in cruise |
|---|---|
| Sapling | d.b.h. (inches)<br>d.b.h. and total height (feet) |
| Pulpwood | d.b.h. (inches)<br>d.b.h. and total height (feet)<br>d.b.h. and height to 4-inch top (feet) |
| Sawtimber | d.b.h. (inches)<br>d.b.h. and total height (feet)<br>d.b.h. and height to 4-inch top (feet)<br>d.b.h. and saw log merchantable height (logs) |

TBCP selects biomass prediction equations based on data from the general geographic area of the user to expand the cruise data to forest stand biomass. For example, Georgia has been divided into three geographic regions, Coastal Plain, Piedmont, and Appalachian Mountains. Biomass weight and volume equations are stored in TBCP for each species or species group by geographic region. The equations used in TBCP were developed by the Utilization of Southern Timber Research Work Unit of the Southeastern Forest Experiment Station in cooperation with the Georgia Forestry Commission, Region 8 of the USDA Forest Service, and forest industries and are published elsewhere (2-7, 9-11). The equations predict the green weights of wood and bark and volume of wood in the total tree above stump and its components (stem, saw log, pulpwood, crown, and crown firewood).

Biomass expressed in cords is calculated from the estimated weight of wood and bark. Weight of wood and bark per cord equivalents are stored in the program by geographic region and species group. These values may be changed by the user when running the program.

Equations for predicting saw log board-foot volume were developed from Mesavage and Girard (8) volume tables and are stored in the program. Mesavage and Girard's tables overestimate the volumes of 10- and 12-inch trees which are generally of a lower form class anyway. Therefore, estimates of 10- and 12-inch trees are made using form class 77 while all other saw log board foot volumes are made using form class 78. The user specifies the desired board foot rule for sawtimber reports. A form class other than 78 may also be requested and the predicted board foot volumes of all d.b.h. classes will be adjusted up or down by 3 percent for each unit change in form class.

The forester or data entry specialist using TBCP answers prompted questions about the tract and the cruiser and certain characteristics of the cruise. The cruise summary tree frequency count data by d.b.h. and height classes for each species or species group are then entered. Stand biomass estimates are based on this information and the stored equations and the results are reported as described below.

## OUTPUT FROM TBCP

Output from TBCP is designed to provide the landowner and forester with information needed to evaluate the forest utilization options available for marketing the timber on a tract and making forest management plans. The output from the program tells the landowner the total biomass above stump on the tract by species or species group. It breaks down that biomass by saw logs, pulpwood, and crown firewood by d.b.h. classes and gives these estimates in tons, cords, cunits and board feet. This information is provided in three basic output tables: A summary table, a table showing biomass by d.b.h. classes, and a table showing saw log board foot volume by d.b.h. class. Output consists of predicted totals only. No statistical sampling inference is calculated since only cruise summary data are entered into the program. Statistics based on plot data is a feature currently under development.

Figure 2 is an example of the output table which shows the predicted gross saw log board foot volume by d.b.h. class, the totals for each species group, and the grand total. Also displayed are the average saw log heights and the number of trees by species and d.b.h. class for each species group. The volumes in this table will be presented in either the Doyle, Scribner, or International ¼-inch log rules as indicated by the user.

The second output table shows the predicted biomass for the total tree and its components (stem to 4-inch top, saw log, stem pulpwood, and crown firewood larger than 4 inches d.o.b. and larger than 2 inches d.o.b.) by d.b.h. classes for each species group (Figure 3). This table also shows the average height and estimated total number of trees per d.b.h. class. At the user's option, this table may appear one or more times each using a different measure (tons, cords, cunits).

```
                          TOTAL BIOMASS CRUISE PROGRAM

LANDOWNER - JOHN DOE                                        CASE NO.-4
ADDRESS - WAYCROSS GA.                                      DISTRICT NO.-12
LOCATION - CHARLTON CO GA.                                  TRACT SIZE (AC) - 40.0
FORESTER - SMITH                                            PHONE - 912-283-5464
ADDRESS - WAYCROSS GA.                                      DATE - 81/07/09.
------------------------------------------------------------------------------------------
DBH      AVERAGE HEIGHT                   TREES           SAWLOG VOLUME SCRIBNER,FC-78.
        PINE   HHWD   SHWD      PINE     HHWD     SHWD    PINE    HHWD     SHWD     ALL
------------------------------------------------------------------------------------------
 IN     ---- LOGS ----          ---- NUMBER ----          ---- THOUSAND BOARD FEET ----

                                      YIELD PER ACRE
10       2.1     .0     .0      11.5      .0       .0      .5      .0       .0      .5
12       2.7    1.6    1.7      10.1     1.1      1.1      .9      .1       .1     1.0
14       3.2    1.6    1.8       7.4      .4      1.9     1.1      .0       .2     1.3
16       3.4    2.0    2.2       3.5      .2       .7      .8      .0       .1      .9
18       3.7    1.8    2.2       1.0      .2       .7      .3      .0       .1      .5
20       4.0    2.0    2.0        .3      .2       .3      .1      .1       .1      .3
22       3.6     .0    2.4        .1      .1       .2      .1      .0       .1      .2
24        .0     .0     .0        .0      .0       .0      .0      .0       .0      .0
26        .0     .0     .0        .0      .1       .0      .0      .1       .0      .1
28        .0     .0     .0        .0      .0       .0      .0      .0       .0      .0
30        .0     .0     .0        .0      .0       .0      .0      .0       .0      .0
------------------------------------------------------------------------------------------
ALL
CLASSES                         33.8     2.3      5.0     3.7      .4       .8     4.9
------------------------------------------------------------------------------------------
```

Figure 2.--An example of output showing estimated gross saw-log board-foot volume by d.b.h. classes.

```
                              TOTAL BIOMASS CRUISE PROGRAM
LANDOWNER - JOHN DOE
ADDRESS - WAYCROSS GA.
LOCATION - CHARLTON CO GA.                                           CASE NO.-4
FORESTER - SMITH                                                     DISTRICT NO.-12
ADDRESS -- WAYCROSS GA.                                              TRACT SIZE(AC)-40.0
                                                                     PHONE-912-283-5464
                                                                     DATE-81/07/09
----------------------------------------------------------------------------------------------
       AVERAGE                                                STEM
DBH    HEIGHT       TREES     TOTAL TREE     SAWLOGS       PULPWOOD       CROWN FIREWOOD
IN     FT.&LOGS     NO.                                                   2 IN.      4 IN.
                              ------------------------------ TONS ------------------------------
                                        YIELD PER ACRE
                                             PINE
 2      20.0        148.6        1.0
 4      32.5         66.4        2.5
 6      48.8         36.5        5.5                         3.7            .1
 8      61.1         16.4        5.4                         4.5            .1
10       2.1         11.5        7.3          4.7            1.2            .2
12       2.7         10.1        9.5          7.0             .9            .3
14       3.2          7.4        9.8          7.8             .4            .4
16       3.4          3.5        7.1          5.3            1.4            .1
18       3.7          1.0        2.7          2.1             .5            .0
20       4.0           .3        1.0           .8             .2            .0
22       3.6           .1         .4           .3             .1            .0
24        .0           .0         .0           .0             .0            .0
26        .0           .0         .0           .0             .0            .0
28        .0           .0         .0           .0             .0            .0
30        .0           .0         .0           .0             .0            .0
                                        HARD HARDWOOD
 2      15.0         25.3         .2
 4      22.0          4.0         .1
 6      44.2          4.2         .6                          .4            .1
 8      47.0          2.0         .6                          .4            .1
10      56.0           .6         .3                          .2            .1
12       1.6          1.1        1.1           .6             .2            .1         .0
14       1.6           .4         .6           .3             .1            .1         .0
16       2.0           .2         .4           .2             .1            .1         .0
18       1.8           .2         .7           .3             .2            .1         .1
20       2.0           .2         .8           .4             .2            .2         .1
22       2.5           .1         .4           .2             .1            .1         .1
24       2.5           .0         .3           .1             .0            .1         .0
26       2.5           .0         .3           .1             .1            .1         .1
28       3.0           .0         .4           .2             .1            .1         .1
30       3.0           .0         .3           .1             .1            .1         .1
                                        SOFT HARDWOOD
 2      23.1         41.1         .5
 4      37.7         23.7        1.4
 6      51.1          9.8        1.3                          .9            .2
 8      59.6          4.7        1.3                         1.0            .2
10      59.0          2.7        1.2                          .9            .2
12       1.7          1.1        1.0           .6             .3            .1         .0
14       1.8          1.9        2.5          1.3             .7            .3         .1
16       2.2           .7        1.3           .7             .3            .2         .1
18       2.2           .7        1.6           .9             .4            .3         .2
20       2.0           .3        1.0           .5             .2            .2         .1
22       2.4           .2         .7           .4             .2            .1         .1
24       2.0           .0         .1           .0             .0            .0         .0
26       2.2           .1         .3           .1             .1            .1         .1
28        .0           .0         .0           .0             .0            .0         .0
30       2.8           .0         .2           .1             .0            .1         .0
```

Figure 3—An example of output showing estimated total tree and tree component biomass by d.b.h. classes.

```
                              TOTAL BIOMASS CRUISE PROGRAM

LANDOWNER - JOHN DOE
ADDRESS - WAYCROSS GA.                                              CASE NO. - 4
LOCATION - CHARLTON CO GA.                                          DISTRICT NO. - 12
FORESTER - SMITH                                                    TRACT SIZE (AC) - 40.0
ADDRESS - WAYCROSS GA.                                              PHONE - 912-283-5464
                                                                    DATE - 81/07/09
-------------------------------------------------------------------------------------------
COMPONENT                        PINE      H-HARDWOOD      S-HARDWOOD        ALL TREES
-------------------------------------------------------------------------------------------

                                      GREEN TONS OF WOOD AND BARK
 TOTAL TREE (ALL)                52.4         7.1             14.4              73.9
 SAPLINGS (BELOW 5 IN)            3.6          .4              1.8               5.8
 TOTAL TREE (ABOVE 5 IN)         48.8         6.7             12.6              68.1
 TOTAL STEM TO 4 IN TOP          40.9         4.6              9.6              55.1
   SAWLOGS 1/                    28.0         2.6              4.6              35.2
   PULPWOOD (ALL)                12.9         2.0              5.0              20.0
     PULPWOOD TREES               8.2         1.0              2.9              12.1
     SAWTIMBER TOPS               4.7         1.0              2.2               7.9
 TOTAL CROWN                      7.9         2.2              3.0              13.0
   CROWN FIREWOOD - 2 IN          1.3         1.4              1.8               4.5
   CROWN FIREWOOD - 4 IN           .0          .6               .8               1.4
                                      CORDS OF WOOD AND BARK 2/
 TOTAL TREE (ALL)                18.7         2.5              5.1              26.3
 SAPLING (BELOW 5 IN)             1.3          .1               .6               2.1
 TOTAL TREE (ABOVE 5 IN)         17.4         2.4              4.4              24.2
 TOTAL STEM TO 4 IN TOP          14.6         1.6              3.4              19.6
   SAWLOGS 1/                    10.0          .9              1.6              12.5
   PULPWOOD (ALL)                 4.6          .7              1.8               7.1
     PULPWOOD TREES               2.9          .3              1.0               4.3
     SAWTIMBER TOPS               1.7          .4               .8               2.8
 TOTAL CROWN                      2.8          .8              1.0               4.6
   CROWN FIREWOOD - 2 IN           .5          .5               .6               1.6
   CROWN FIREWOOD - 4 IN           .0          .2               .3                .5
                                      VOLUME OF WOOD (CUNITS)
 TOTAL TREE (5 IN AND ABOVE)     12.6         1.7              3.6              17.9
 TOTAL STEM TO 4 IN TOP          10.9         1.2              2.8              14.9
   SAWLOGS 1/                     7.9          .7              1.3               9.9
   PULPWOOD (ALL)                 3.0          .5              1.5               5.0
     PULPWOOD TREES               2.2          .2               .9               3.4
     SAWTIMBER TOPS                .8          .3               .6               3.4
 TOTAL CROWN                      1.8          .5               .8               3.0
   CROWN FIREWOOD - 2 IN           .4          .3               .5               1.2
   CROWN FIREWOOD - 4 IN           .0          .1               .2                .3

                                SAWLOG BOARD-FOOT VOLUME -- (MBF)
 SAWLOGS (DOYLE)                  2.3          .3               .5               3.2
 SAWLOGS (SCRIBNER)               3.7          .4               .8               4.9
 SAWLOGS (INT. ¼)                 4.5          .4               .9               5.8
                                 (BASAL AREA PER ACRE (SQ.FT.))
 SAPLING TREES                     9            0                2               11
 PULPWOOD TREES                   12            1                5               18
 SAWTIMBER TREES                  29            3                6               38
 ALL TREES                        50            4               13               67
-------------------------------------------------------------------------------------------

1-SAWLOG MERCHANTABLE TOP; 7-INCH DOB FOR PINE, 9-INCH FOR HARDWOODS OR THRU LOG GRADE
  NUMBER 3 MERCHANTABILITY
2-POUNDS PER CORD: PINE=5600., SOFT HARDWOOD=5700., HARD HARDWOOD=5700.
```

Figure 4.—An example of output summarizing the predicted total tree and tree component weight and volume per acre.

The summary table (Figure 4) shows the total biomass of all trees on the tract or per acre in tons, cords, and cunits for each species group and all species combined. The total biomass is also broken down by saplings, trees 5.0 inches d.b.h. and larger, stem to 4-inch top, and crown. The biomass in the stem to 4-inch top is divided into saw logs and pulpwood. The pulpwood is further subdivided to show that which comes from pulpwood size trees as opposed to that from the tops of sawtimber size trees. The amount of crown firewood that is greater than or equal to 2-inch d.o.b. small end and greater than or equal to 4 inches d.o.b. small end is also shown. Also displayed are the total saw log board foot volumes for each species group by desired board foot rule. Finally, the estimated average basal area per acre in square feet is given by tree size classes and species group.

## USE AND INTERPRETATION OF OUTPUT

The output produced by TBCP is designed to provide gross total tree and tree component stand biomass estimates. Thus, foresters and landowners should interpret and use these biomass estimates carefully. Estimates are made assuming the most efficient utilization during timber harvesting. If the loggers fail to cut saw logs to the upper stem limit cruised, cut stem pulpwood to only a 6-inch rather than a 4-inch small end diameter, or fail to utilize all branches greater than 4 inches for firewood, TBCP will overestimate product yields. Therefore, users should adjust saw log, pulpwood, and firewood estimates to coincide with local harvesting practices.

The output tables showing biomass by d.b.h. classes (Figure 3) and the summary table (Figure 4) contain weight and volume estimates for the basic components of the tree. These basic values allow users to combine component estimates to stimulate harvesting practices in their area. For example, in some areas only hardwood saw logs can be sold commercially and no market for hardwood pulpwood exists. Stem pulpwood estimates could therefore be combined with crown firewood and marketed as such.

TBCP assumes that the cruise was a random sample and will therefore lead to unbiased estimates. However, these estimates may contain errors due not only to harvesting differences but also associated with the biomass prediction equations and timber cruise procedures. When timber is 100% cruised, the error associated with the cruise is minimized since all trees are tallied. Preliminary tests of TBCP using this cruise procedure indicate that predicted total tree, total stem to a 4-inch top, and saw log weights and volumes will generally be within 10% of the actual weights and volumes, if d.b.h. and some estimate of height are provided the program. Biomass of upper stem pulpwood and crown firewood varies considerably more. Estimates of these components were found to vary by as much as 40% from the observed values. TBCP users should use these component estimates carefully until they gain field experience as to their reliability. Biomass estimates based on fixed area plots, point sampling or strip cruising can contain more error than those based on 100% cruise. To minimize sampling error, plots and strips must be located without bias, border trees must be measured carefully to determine if they are in or out of the cruise and a sufficient number of plots and strips must be taken.

## CURRENT APPLICATIONS

TBCP is written in Fortran IV and currently operates on the CDC CYBER 170/730 computer at the University of Georgia Office of Computing Activities in Athens. The Total Biomass Cruise Program is accessible through the Forestry Weather Interpretation System (FWIS) communication network monitored by the Southeastern Forest Experiment Station Southern Forest Fire Laboratory for use by the Georgia Forestry Commission. The Georgia Forestry Commission has a computer terminal at each District office in the State on which service foresters can access TBCP to input cruise data and receive estimates of total tree and forest product yields for a landowner. A batch version (card input and line printer output) is also available.

The program in part or in total has been requested for use by other states, other units of the Forest Service, other federal agencies and several private forestry organizations. Studies to further test the program results are also underway or are being planned.

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*In this total tree harvesting operation, the best logs are reserved as saw timber, while the remainder will go for wood energy purposes.*

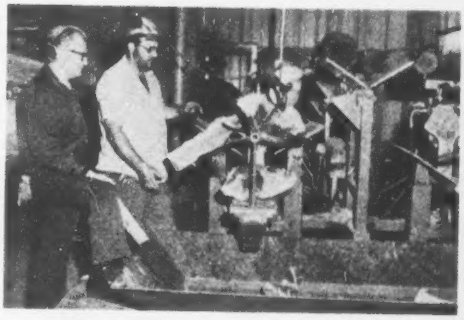
*A load of quality sawlogs on the way to a lumber mill.*

*Tree length logs are unloaded at a concentration yard.*

*These tree length logs will be used to the best advantage. Some will be utilized as saw timber, while others will be processed as energy wood.*

*A feller buncher clips a tree into at ground level in a harvesting operation of low quality hardwoods destined for energy wood utilization.*

*Low quality timber is automatically split in this firewood processing operation.*



*A conveyor carries firewood to a loading ramp at one of Georgia's largest firewood processing plants.*

*In this low quality hardwood harvesting operation, the timber will be used for energy purposes.*

# GEORGIA FOREST RESEARCH PAPER

**22**

AUGUST, 1981

# TOTAL TREE AND FIREWOOD WEIGHTS AND VOLUMES OF SCRUB OAKS IN THE GEORGIA SANDHILLS

BY

W. HENRY MCNAB

RESEARCH DIVISION

GEORGIA FORESTRY COMMISSION

# AUTHOR

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# ACKNOWLEDGMENT:

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# TOTAL TREE AND FIREWOOD WEIGHTS AND VOLUMES OF SCRUB OAKS IN THE GEORGIA SANDHILLS

BY

W. HENRY MCNAB

## INTRODUCTION

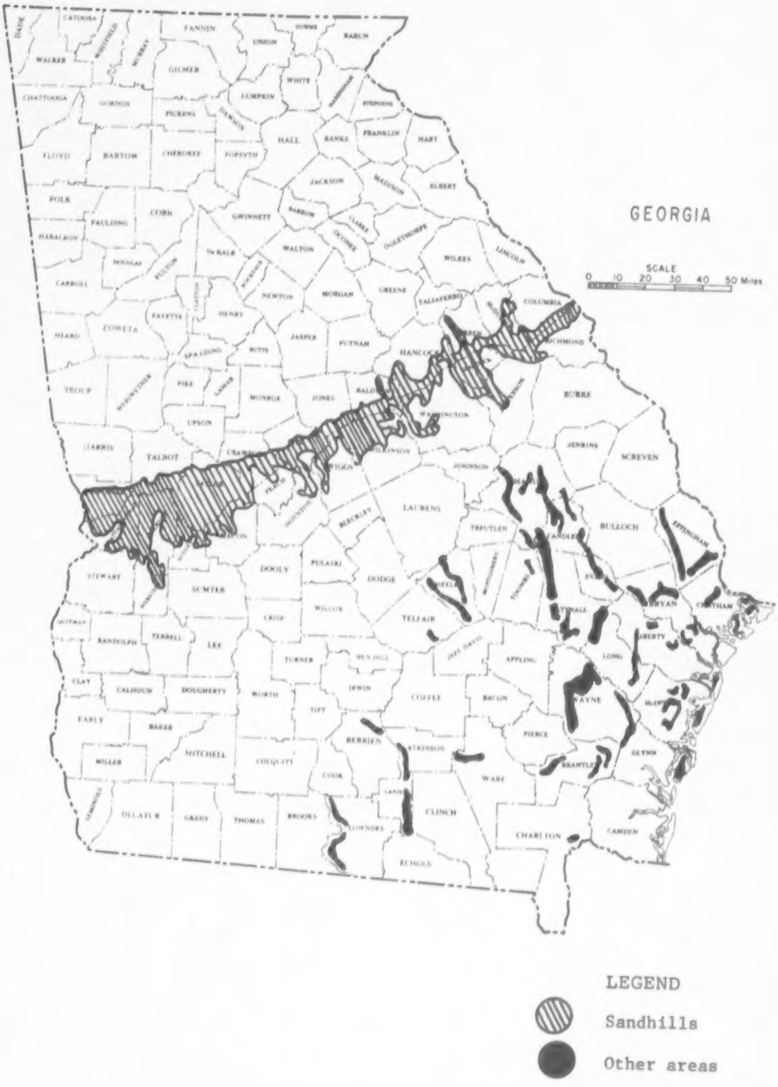
The southern scrub oak forest type, as the name implies, is a mixture of small, poor quality oak species, often with an overstory of scattered longleaf pines. This association typically consists of a mixture of four oak species: turkey oak (Q. laevis), bluejack oak (Q. incana), sand post oak (Q. stellata var. margaretta), and blackjack oak (Q. marilandica). Along the eastern coastal region, sand live oak (Q. virginiana var. geminata) may also be present. This is the smallest hardwood type recognized by the forest survey in Georgia, occupying about ½ million acres. It occurs throughout the State (Knight and McClure 1974), but over 50 percent is in the sandhills physiographic region, a narrow belt of droughty, deep sands separating the Piedmont and Coastal Plains (Figure 1) (Perkins and Shaffer 1977). The sandhills, and scrub oaks, are most extensive in west central Georgia, in Taylor, Marion, and Webster counties. Similar droughty sites are also present in southeastern Georgia along the east side of many coastal plains rivers, particularly the Ogeechee, and on sandstone rock outcrops (Wharton 1980).

Wood production on sandhill sites is marginal from the native oaks, only 20 to 50 cubic feet annually. It can be improved through intensive site preparation and reforestation with sand pine (Preston and Price 1979). Prior to site preparation, scrub oaks are seldom harvested for conventional forest products because they are too small and poorly formed. However, the increased demand for fuelwood may present more opportunity for utilization of scrub oaks by whole tree chipping (Butts and Preston 1979).

Scrub oaks seem to be an ideal fuelwood species; their wood is dense and heavy and they occur on sites which can be harvested year round. Their small size makes them costly to harvest manually, but they are potentially suitable for harvest with mobile whole-tree chippers. In some areas, firewood for the home market may be a more immediately marketable roundwood product. Due to the low value of scrub oaks, no information has been available for estimating their weights and volumes to determine product yield of whole-tree chips or firewood.

To encourage greater utilization of the scrub oak forest resource, a cooperative study with the Georgia Forestry Commission was undertaken to develop the prediction equations and tables contained in this publication. Included here are tables for prism cruising to allow conversion of tree counts directly into biomass estimates (Phillips and Saucier 1981).

Figure 1.--Areas of deep sandy soils in Georgia. The concentration running through the center of the State is called the sandhills. (Map from Perkins and Shaffer 1977).



## METHODS

Scrub oaks were sampled at two locations in Georgia: near Butler in Taylor County, and at Fort Gordon in Richmond County. At each location, about 60 trees representing the diameter range of the various oak species were felled for measurement, weighing, and sampling of wood characteristics. In addition to total height, the height to a 2-inch d.o.b. top limit was measured on each tree to obtain the weight and volume of firewood. The entire tree was then weighed on a portable field scale. The branches were then removed and the stem alone was reweighed. Since field work was carried out in November, after leaves had fallen, foliage was not sampled.

A total of 124 trees were sampled, ranging from 0.9 to 6.8 inches d.b.h. and from 9 to 38 feet in height, Table 1. The average age was 28 years and few trees larger than 7 inches d.b.h. were present in the sampled stands. Average green and dry weights of the sample trees are shown in Table 2.

Sample disks were cut from the stem and branches, sealed in plastic bags, and returned to the laboratory for processing. Additional data on wood properties were obtained from the disks, including percent bark by weight, moisture content of wood and bark, and specific gravity of wood and bark. (A computer program was used to calculate cubic volume from the field and laboratory data for each tree.) Data from the four species were combined for analysis to obtain results that would be easy to apply to typical stands of mixed scrub oaks. Prediction equations were developed to estimate weight and volume of the total tree and of firewood from d.b.h. alone and from d.b.h. and total height.

## RESULTS AND DISCUSSION

### WOOD AND BARK PROPERTIES

The scrub oaks we sampled have properties that make them ideal as fuelwood, Table 3. In comparison to other hardwood species commonly used for fuel, scrub oak wood is denser and drier. Although bark content is somewhat higher than for other species--over 25 percent for the total tree on a green weight basis--bark properties, including heat content, are favorable for use as fuel. For the main stem, bark content ranged from 20 percent for 6-inch d.b.h. trees to 44 percent for 1-inch trees.

### TOTAL TREE AND FIREWOOD GREEN WEIGHT

Equations for predicting green weight of wood and bark for the total tree and firewood were developed using d.b.h. alone and in combination with total height. Estimates of green weight of the total tree and firewood to a 2-inch d.o.b. top, based on d.b.h. alone, are presented in Table 4. Similar predicted weights from equations utilizing both d.b.h. and height are presented in Tables 5 and 6. Where the scrub oak stand being cruised has similar diameter to total height relationships as the data utilized for the equations (Table 1), use of d.b.h. alone in a local volume table will provide sufficiently accurate estimates. However, where the mean heights differ by diameter class, more accurate results will be obtained by using total height in the cruise, especially for trees greater than 6 inches d.b.h. The equations presented with tables 5 and 6 can be used to construct a new local volume table for a particular tract, based on d.b.h. alone.

Estimates of dry weight of the total tree or of firewood may be obtained using moisture content data presented in Table 3. Mean moisture content was 65 percent of the dry weight for the wood and bark of the average total tree. Thus, dividing green weights by 1.65 converts green weight estimates to dry weight. For example, Table 4 shows that a scrub oak 5 inches d.b.h will have an average green weight of about 207 pounds; dividing by 1.65 yields a dry weight of about 125 pounds dry. Mean moisture content of the firewood portion of the tree was 66 percent.

The relative amounts of firewood and crown material in scrub oaks are shown in Figure 2. Only small amounts of firewood are present in trees smaller than 3 inches d.b.h. For example, 2-inch trees had less than 1/3 of their weight in stem material, but trees 3 inches d.b.h. and larger, have greater than 50 percent of their weight in stem material or potential firewood.

### TOTAL TREE AND FIREWOOD VOLUME

Presented in Table 7 are estimates of total volume and firewood volume based on d.b.h. alone; Tables 8 and 9 show similar estimates using d.b.h. and total height. The data from both tables provide similar estimates of cubic volume around the mean value of tree sampled. However, as previously mentioned for tree weight, height estimates will improve accuracy where the trees being cruised are shorter or taller than the trees we sampled.

These volume tables may be used with locally available factors for converting tree volume to cordwood volume. For example, assuming that a cord of stacked wood contains 76 cubic feet of wood and bark, then a 4-inch tree with 1.15 cubic feet of wood and bark is equivalent to 0.015 cord. About 66 trees of this size would be needed to make a cord of stacked wood.

### PRISM CRUISING FACTORS

Prism cruising is a fast and accurate method for estimating both stand basal area and biomass in a single operation. Factors for converting prism cruise data (BAF = 10) to biomass were computed for total tree and firewood weight for individual d.b.h. classes, Table 10. For example, a stand with an average of 30 square feet of basal area in 5-inch trees would contain 22.8 tons per acre of green biomass; 15 tons of the total biomass would be in the form of firewood greater than 2 inches diameter. On the average, there are about 2 tons of biomass per acre for each 3 square feet of scrub oak basal area.

### STAND BIOMASS ESTIMATES

Three scrub oak stands of average quality and stocking were cruised at the Fort Gordon site to determine stocking and biomass characteristics. As shown in Table 11, the stands averaged 467 trees per acre with a mean tree d.b.h. of 4.0 inches. The total green biomass was estimated to be 35.8 tons per acre. About 34 tons per acre of biomass are in trees 3 inches d.b.h. and larger. Few stems smaller than 3 inches d.b.h. were present in these three stands, and they contained only about 1 ton per acre of biomass. The biomass harvest is somewhat less than would be available from more fertile sites. However, it is well above the 15-20 green tons per acre estimated to be needed for economical harvest with a mobile biomass harvester such as recently developed by Georgia-Pacific for small trees and brush (Anon. 1980).

If these average quality stands were harvested for solid firewood, they would yield about 9 cords of wood per acre.

Figure 2.--Estimated total green weight of scrub oaks by d.b.h. class, subdivided by firewood and branch components.

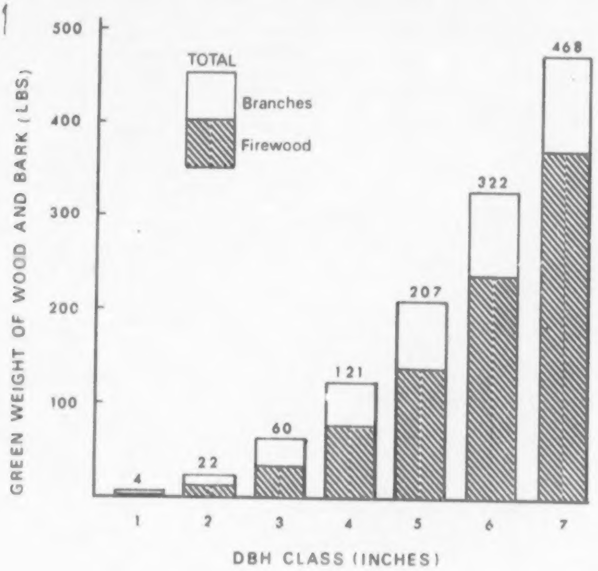


Table 1.-- Means and ranges of d.b.h. and height of the sampled scrub oak trees.

| D.b.h. class (Inches) | Sample trees | D.b.h. | | Total height | | Merch. height | | Age Avg. |
|---|---|---|---|---|---|---|---|---|
| | | Avg. | Range | Avg. | Range | Avg. | Range | |
| | Number | - - Inches - - | | - - - - - - Feet - - - - - - | | | | Years |
| 1 | 8 | 1.2 | 0.9-1.5 | 11.9 | 9-14 | 1.0 | 0.2- 2.2 | 18 |
| 2 | 23 | 2.0 | 1.6-2.5 | 17.1 | 10-22 | 4.8 | 1.0-10.1 | 21 |
| 3 | 25 | 3.0 | 2.6-3.5 | 23.6 | 18-28 | 13.0 | 7.4-18.8 | 28 |
| 4 | 24 | 4.1 | 3.6-4.5 | 26.5 | 19-33 | 17.6 | 12.3-22.1 | 29 |
| 5 | 23 | 5.0 | 4.6-5.5 | 29.2 | 21-37 | 20.5 | 15.0-28.0 | 34 |
| 6 | 15 | 6.0 | 5.6-6.5 | 30.3 | 24-38 | 22.2 | 17.1-28.4 | 38 |
| 7 | 2 | 6.7 | 6.6-6.8 | 30.5 | 28-33 | 21.2 | 17.0-25.4 | 35 |
| All classes | 124 | 3.7 | .9-6.8 | 23.8 | 9-38 | 14.9 | 0.2-28.4 | 28 |

Table 2.--Average green and dry weight of firewood and the total tree wood and bark for 124 scrub oaks sampled at two locations in Georgia.

| D.b.h. class (Inches) | Tree weight | | Firewood weight | | Volume | | Bark proportion |
|---|---|---|---|---|---|---|---|
| | Green | Dry | Green | Dry | Tree | Firewood | |
| | - - - - - - Pounds - - - - - - - | | | | - - Cu Ft - - | | Percent |
| 1 | 6.8 | 4.2 | 1.5 | 1.0 | 0.11 | 0.04 | 43.2 |
| 2 | 23.5 | 14.3 | 9.9 | 6.0 | 0.36 | 0.18 | 36.0 |
| 3 | 62.3 | 38.0 | 40.1 | 24.4 | 0.94 | 0.66 | 29.5 |
| 4 | 129.8 | 79.0 | 83.7 | 50.6 | 1.90 | 1.32 | 27.0 |
| 5 | 219.4 | 132.6 | 137.1 | 82.2 | 3.24 | 2.17 | 26.4 |
| 6 | 337.2 | 205.5 | 205.9 | 123.8 | 4.91 | 3.19 | 26.1 |
| 7 | 411.4 | 253.5 | 223.3 | 136.1 | 5.89 | 3.47 | 27.9 |
| Average | 130.8 | 79.6 | 83.5 | 50.4 | 1.92 | 1.32 | 30.5 |

Table 3.--Physical properties of wood and bark from 124 scrub oaks in Georgia sandhills.

| Tree component | Property | | |
|---|---|---|---|
| | Moisture content[1] | Specific gravity | Bark content |
| | Percent | | Percent |
| Stem | | | |
| Wood | 70 | 0.67 | 22.6 |
| Bark | 52 | .60 | - |
| Wood & bark | 66 | .66 | - |
| Branch | | | |
| Wood | 59 | .72 | 32.4 |
| Bark | 73 | .57 | - |
| Wood & bark | 64 | .67 | - |
| Total Tree | | | |
| Wood | 67 | .69 | 25.9 |
| Bark | 59 | .59 | - |
| Wood & bark | 65 | .66 | - |

[1] Determined on a dry weight basis.

Table 4.--Predicted total tree and firewood green weight of wood and bark of scrub oaks based on d.b.h. alone.[1]

| D.b.h. (Inches) | Tree component | |
|---|---|---|
| | Total | Firewood |
| | - - - - - - Pounds | - - - - - - - - |
| 1 | 4 | 1 |
| 2 | 22 | 9 |
| 3 | 60 | 30 |
| 4 | 121 | 71 |
| 5 | 207 | 136 |
| 6 | 322 | 232 |
| 7 | 468 | 365 |

[1] Tabular values derived from equations:

$$Y \text{ (total tree)} = 4.20303(D^2)^{1.21089}$$

$$Y \text{ (firewood)} = 1.20425(D^2)^{1.46787}$$

where:

Y = weight in pounds

D = d.b.h. in inches

Table 5.--Predicted green weight of scrub oak total tree wood and bark based on d.b.h. and total height.[1]/[2]/

| D.b.h. (Inches) | Total tree height | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 |
| | - - - - - - - - - - - - - - | | | Pounds | - - - - - - - - - - - - - - | | | |
| 1 | 4 | 5 | 7 | 9 | 10 | | | |
| 2 | 14 | 20 | 26 | 32 | 38 | 44 | | |
| 3 | 29 | 43 | 56 | 69 | 82 | 94 | 107 | |
| 4 | 50 | 73 | 96 | 118 | 140 | 162 | 183 | 205 |
| 5 | 76 | 111 | 145 | 179 | 213 | 246 | 278 | 311 |
| 6 | | 156 | 205 | 252 | 299 | 346 | 392 | 437 |
| 7 | | | 273 | 337 | 399 | 462 | 523 | 584 |
| 8 | | | | 432 | 513 | 593 | 672 | 750 |

[1]/Tabular values computed from equation:

$$Y = 0.42876(D^2H)^{0.93745}$$

where:

$Y$ = weight in pounds

$D$ = d.b.h. in inches

$H$ = total height in feet

[2]/Blocked-in area indicates range of data.

Table 6.--Predicted green weight of scrub oak firewood wood and bark to 2-inch top based on d.b.h. and total height.[1] [2]

| D.b.h. (Inches) | Total tree height | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 |
| | Pounds | | | | | | | |
| 1 | 1 | 2 | 2 | 3 | 4 | | | |
| 2 | 5 | 8 | 11 | 14 | 17 | 21 | | |
| 3 | 12 | 20 | 27 | 36 | 44 | 52 | 61 | |
| 4 | 24 | 38 | 53 | 69 | 85 | 101 | 118 | 135 |
| 5 | 40 | 64 | 89 | 115 | 142 | 169 | 197 | 226 |
| 6 | | 97 | 135 | 176 | 215 | 257 | 300 | 343 |
| 7 | | | 193 | 249 | 307 | 367 | 427 | 489 |
| 8 | | | | 338 | 417 | 498 | 581 | 665 |

[1] Tabular values computed from equation:

$Y = 0.07019(D^2H)^{1.14954}$

where:

Y = weight in pounds

D = d.b.h. in inches

H = total height in feet

[2] Blocked-in area indicates range of data.

Table 7.--Predicted total tree and firewood cubic volume of wood and bark for scrub oaks based on d.b.h. alone.[1]

| D.b.h. (Inches) | Tree component | |
|---|---|---|
| | Total | Firewood |
| | cubic feet | |
| 1 | 0.07 | 0.03 |
| 2 | .35 | .18 |
| 3 | .91 | .53 |
| 4 | 1.79 | 1.15 |
| 5 | 3.04 | 2.11 |
| 6 | 4.68 | 3.45 |
| 7 | 6.75 | 5.23 |

[1] Tabular values derived from equation:

$$Y \text{ (total tree)} = 0.06709(D^2)^{1.18482}$$

$$Y \text{ (firewood)} = 0.02730(D^2)^{1.35056}$$

where:

Y = volume in cubic feet

D = d.b.h. in inches

Table 8.--Predicted volume of scrub oak total tree wood and bark.[1] [2]

| D.b.h. (Inches) | Total tree height | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 |
| | - - - - - - | - - - - - - | - - - - - - | cubic feet | - - - - - - | - - - - - - | - - - - - - | - - - - - - |
| 1 | 0.06 | 0.09 | 0.11 | 0.14 | 0.16 | | | |
| 2 | 0.21 | 0.31 | 0.40 | 0.49 | 0.58 | 0.67 | | |
| 3 | 0.45 | 0.65 | 0.84 | 1.03 | 1.22 | 1.41 | 1.59 | |
| 4 | 0.76 | 1.10 | 1.43 | 1.75 | 2.07 | 2.39 | 2.70 | 3.01 |
| 5 | 1.14 | 1.65 | 2.15 | 2.64 | 3.12 | 3.59 | 4.06 | 4.53 |
| 6 | | 2.31 | 3.01 | 3.69 | 4.36 | 5.02 | 5.68 | 6.33 |
| 7 | | | 3.99 | 4.90 | 5.79 | 6.67 | 7.54 | 8.40 |
| 8 | | | | 6.26 | 7.40 | 8.52 | 9.63 | 10.74 |

---

[1] Tabular values computed from equation:

$$Y = 0.00714(D^2H)^{0.91840}$$

where:

Y = volume in cubic feet

D = d.b.h. in inches

H = total height in feet

[2] Blocked-in area indicates range of data.

Table 9.--Predicted volume of scrub oak wood and bark firewood to 2-inch top.[1] [2]

| D.b.h. (Inches) | Total tree height | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 |
| | cubic feet | | | | | | | |
| 1 | 0.02 | 0.04 | 0.05 | 0.06 | 0.07 | | | |
| 2 | 0.10 | 0.15 | 0.21 | 0.26 | 0.32 | 0.37 | | |
| 3 | 0.23 | 0.36 | 0.49 | 0.61 | 0.74 | 0.88 | 1.01 | |
| 4 | 0.43 | 0.66 | 0.89 | 1.13 | 1.37 | 1.61 | 1.85 | 2.09 |
| 5 | 0.69 | 1.05 | 1.43 | 1.80 | 2.19 | 2.57 | 2.96 | 3.35 |
| 6 | | 1.55 | 2.09 | 2.65 | 3.21 | 3.78 | 4.35 | 4.93 |
| 7 | | | 2.90 | 3.67 | 4.45 | 5.23 | 6.02 | 6.82 |
| 8 | | | | 4.86 | 5.89 | 6.93 | 7.98 | 9.04 |

[1] Tabular values computed from equation:

$$Y = 0.00203(D^2H)^{1.05468}$$

where:

$Y$ = volume in cubic feet

$D$ = d.b.h. in inches

$H$ = total height in feet

[2] Blocked-in area indicates range of data.

Table 10.-- Factors for converting prism cruise data (BAF = 10) to estimated total tree and firewood weight of scrub oaks in the Georgia sandhills.

| D.b.h. class (inches) | Total height | Trees per acre | Tree component | |
|---|---|---|---|---|
| | | | Total | Firewood |
| | feet | number | tons/10 $ft^2$ basal area | |
| 1 | 11.9 | 1833 | 4.0 | 1.1 |
| 2 | 17.1 | 458 | 5.2 | 2.1 |
| 3 | 23.6 | 204 | 6.6 | 3.4 |
| 4 | 26.5 | 115 | 7.2 | 4.2 |
| 5 | 29.2 | 73 | 7.6 | 5.0 |
| 6 | 30.3 | 51 | 7.7 | 5.6 |
| 7 | 30.5 | 37 | 7.5 | 5.8 |

Table 11.--Scrub oak tree stocking and estimated green weight of wood and bark by d.b.h. class for three stands sampled at Fort Gordon, Ga.

| D.b.h. classes (inches) | Tree stand | | | | Total | |
|---|---|---|---|---|---|---|
| | A | B | C | Mean | Biomass | Firewood |
| | trees per acre | | | | tons/acre | $ft.^3$/acre |
| 1 | 100 | 50 | 17 | 56 | .12 | 1.5 |
| 2 | 162 | 50 | 17 | 76 | .86 | 13.5 |
| 3 | 162 | 100 | 50 | 50 | 3.12 | 55.2 |
| 4 | 50 | 75 | 67 | 64 | 3.86 | 73.8 |
| 5 | 25 | 150 | 50 | 75 | 7.77 | 158.2 |
| 6 | 38 | 50 | 33 | 40 | 6.44 | 138.1 |
| 7 | 12 | 50 | 33 | 32 | 7.49 | 167.5 |
| 8 | 0 | 25 | 33 | 19 | 6.14 | 142.6 |
| Total | 550 | 550 | 300 | 467 | 35.80 | 735.4 |

# SUMMARY

Fuelwood is one merchantable product for which small scrub oaks are suitable. The wood of these trees is as dense as hickory and relatively low in moisture--both desirable qualities for fuelwood. The major drawback is the small size of the trees, which will increase harvesting costs. More than 30 tons of green biomass per acre were present in trees 3 inches d.b.h. and larger in the sample stands, which were of average quality.

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# GEORGIA FOREST RESEARCH PAPER

## 25

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# CREOSOTE PRODUCTION FROM BEETLE INFESTED TIMBER

BY

J. FRED ALLEN AND TIMOTHY T. MAXWELL

RESEARCH DIVISION

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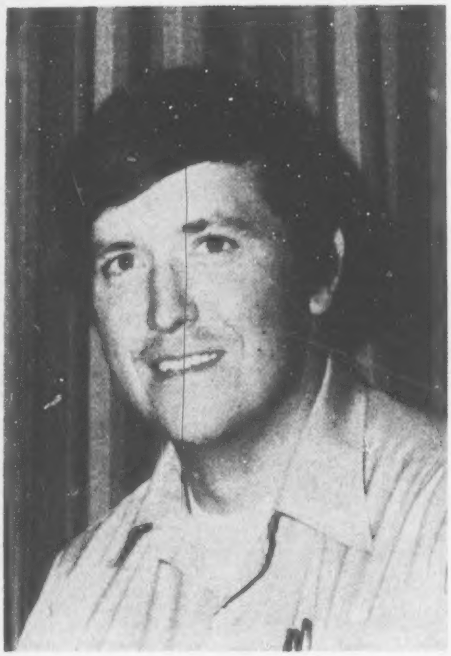

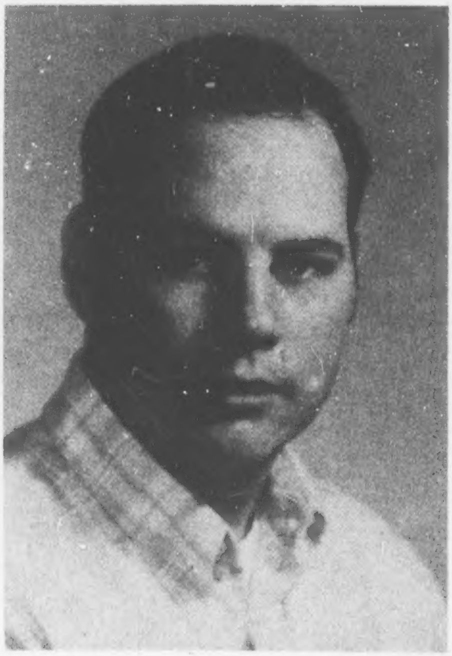

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# CREOSOTE PRODUCTION FROM BEETLE INFESTED TIMBER

BY

J. FRED ALLEN AND TIMOTHY T. MAXWELL

## ABSTRACT

Tests were run to determine the amount of creosote accumulation produced by burning timber killed by Southern Pine Beetles in airtight wood burning stoves. Four stove and chimney assemblies were set up and burned for approximately one month. The creosote accumulation was measured by weighing the chimney components before and after the tests.

In addition to beetle-killed pine, green pine, green hardwood, and seasoned hardwood were also considered in the study; one was burned in each of the four stoves. The results showed that all of the woods produced significant levels of creosote with the stoves set at low air inlet rates. The beetle-killed pine produced the most creosote, while the green pine produced the least. The seasoned hardwood produced more creosote than did the green hardwood.

# INTRODUCTION

Creosote is a common problem to wood burners. Creosote is a sticky, tar-like substance that accumulates in the chimneys and flues of wood burning appliances, especially "airtight" stoves and heaters. Incomplete combustion of the wood, a problem typical of airtight wood burning stoves, allows combustible compounds to escape from the combustion chamber of the stove. These combustible materials (vapors, liquid droplets, or solid particles) condense and stick to the chimney and flue surfaces which are relatively cooler than the combustion products. The resulting deposits are commonly called creosote.

Creosote deposits can in the worse cases actually block off the flue of an appliance. This would render the appliance unusable until the flue is cleaned. However, of greater danger is the possibility of the creosote igniting and burning inside the flue or chimney. When a creosote fire (the burning of the creosote inside the chimney) does occur, the temperatures attained in the chimney will be higher than during normal operation of the appliance. These excessive temperatures may damage the chimney and overheat nearby combustible structures. The end result would be a home fire.

The production and accumulation of creosote in the chimney of a wood burning appliance is a safety problem. If the creosote problem is to be alleviated, the mechanisms of creosote production and accumulation must be better understood. Obviously a more complete combustion process would lower the rate of creosote combustion. Also, if the flue gases are kept relatively hot as they pass through the chimney, less creosote will condense and deposit.

The chimney can be insulated and kept inside the heated part of the home as much as possible to reduce the heat loss from the flue gases. However, if the flue gases are kept too warm, energy will be thrown away up the chimney. Flue temperatures should be between 350°F and 500°F at the exit from the chimney for ideal operation.

The combustion process is controlled by the amount of air admitted to the combustion chamber, the mixing of the air with the fuel (combustible gases produced by the wood), the temperature of the air-fuel mixture and by the fuel itself. The stove design, or lack of design, will determine to a large extent the mixing processes and the temperature of the combustion process. However, the homeowner or operator controls the rate at which air is admitted to the stove and the type of fuel that is burned in the stove. Tests at the Auburn Wood Burning Laboratory (AWL) [1] indicate that the mode of operation or air inlet setting is by far the most significant parameter to creosote production.

The type of wood and the moisture content of the wood have long been thought to be important parameters in creosote production. Softwoods, pine in particular, and green or wet wood of any variety are generally accused of producing excessive amounts of creosote while seasoned hardwoods are heralded as being relatively creosote free. As a result of its reputation of producing excessive creosote and because pine is significantly less dense than most hardwoods, and hence burns more rapidly, most homeowners have excluded pine as a potential fuel source for wood burning stoves.

Between 1979 and 1980, southern pine beetles, the major insect killer of southern pines, destroyed approximately 856,000 cords of pine timber. Forest industries salvaged 64 percent of the infested timber [2]. The 36 percent not salvaged could be used as a source of energy for homes that have wood burning appliances. There is an increasing demand for wood for fuel; hence, this extensive source of fuel wood cannot be overlooked.

The tests run at Auburn show that the type and moisture content of wood burned does affect creosote formation to a small degree, but generally not in the manner traditionally thought. That is green wood and softwoods (pine in particular) actually produced less creosote than did the seasoned woods and hardwoods. This indicates that pine cannot be rejected as a source of fuel wood for wood burning stoves because of creosote production characteristics. However, all of the tests conducted at AWL were laboratory tests that were not intended to reproduce exactly conditions of a stove in a home. This study was undertaken to compare the creosote production characteristics of pine and other woods under conditions representative of a typical stove installation. In particular, the objectives were:

1) to determine if beetle-killed pine can be burned in wood burning stoves without excessive creosote production.
2) to determine how the creosote production from beetle-killed pine compares with the creosote production of other wood species at various moisture contents.

# TEST SET-UP AND PROCEDURE

The test program consisted of operating four wood burning stoves for approximately one month. Periodically, the mass of creosote deposits in the chimney of each stove was measured. A different type wood was used to fire each stove; hence, the relative amounts of creosote deposit produced by each type wood could be determined.

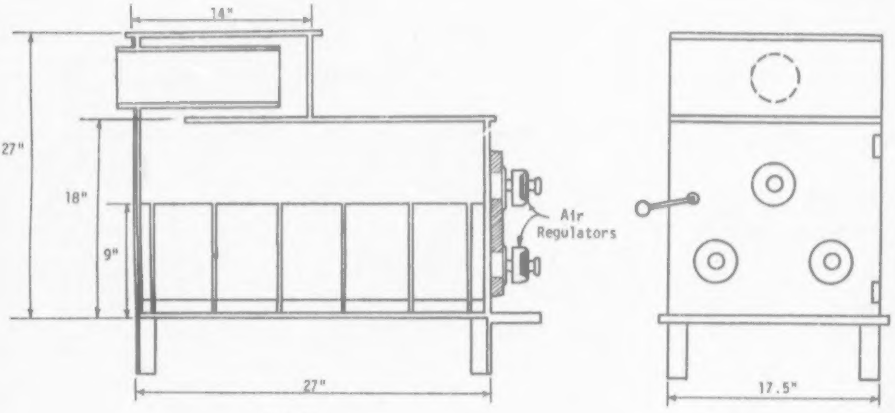
The stoves were radiant units made of plate steel in a typical two step design. Figure 1 shows a schematic diagram of the type stove used. The four stoves were supplied by the same manufacturer and were hence, essentially identical. The stove pipe connections consisted of an adapter, a 90° elbow and three 24 inch long sections of 6 inch diameter, 24 gauge stove pipe. The stove pipe was joined to a prefabricated chimney that included a roof support section, two 30 inch long sections and a chimney cap. The prefabricated chimney was a typical insulated type chimney (two stainless steel walls with 1 inch of solid packed insulation between). Figure 2 shows a schematic diagram of the stove and chimney arrangement. The four units were located in a row approximately 6 feet apart.

The stoves were operated at a very low air inlet setting to typify home operation. A thermometer was installed midway up the first section of single wall stove pipe. The air inlets on each stove were adjusted as required to maintain a flue gas temperature between 300-350°F.

The stoves were charged with wood as needed to maintain the desired flue gas temperature as described above. Generally, this required chargings in the morning and afternoon. All of the stoves were fully charged at the end of each working day and allowed to burn overnight.

Each time a stove was charged, the mass of wood input, the time, and the ambient temperature were recorded. Before installation each section of stove pipe and chimney were weighed and recorded. After ten days of operation, the stove pipe and chimney sections were carefully disassembled and reweighed. To prevent loss of creosote, the sections were tapped lightly so that the very loose creosote deposits were removed. The sections were again reweighed and then reassembled on the stoves from which they came. After twenty days of operation, the weighing procedure was repeated. This time the chimneys were reassembled on different stoves. Finally, after thirty-three days of operation, the chimneys were disassembled, and a last weighing was carried out.

Two stoves were fired with mixed hardwoods (oak and hickory), one burning seasoned hardwood, the other green hardwood. The other two stoves were fired with beetle-killed pine and green pine respectively. All of the wood was in the form of split and round pieces. Random samples were taken from each wood group at various times during the tests and the moisture content was measured.



Side View

Front View

Figure 1 Schematic Diagram of Stove Used in Test

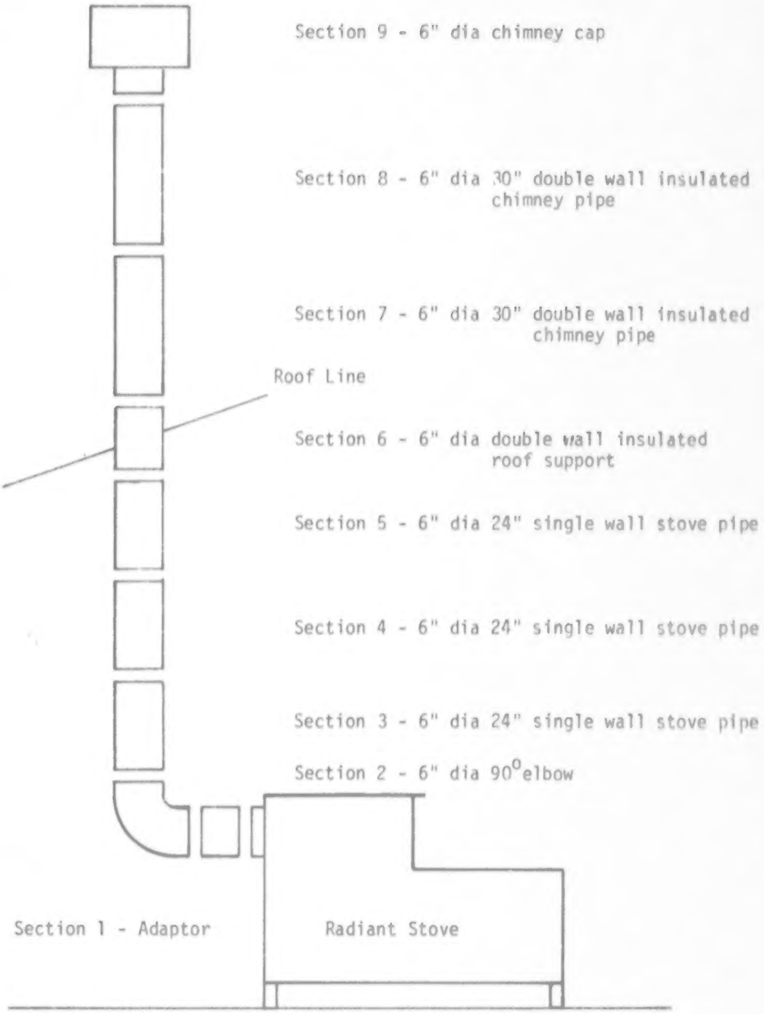

Section 9 - 6" dia chimney cap
Section 8 - 6" dia 30" double wall insulated chimney pipe
Section 7 - 6" dia 30" double wall insulated chimney pipe
Roof Line
Section 6 - 6" dia double wall insulated roof support
Section 5 - 6" dia 24" single wall stove pipe
Section 4 - 6" dia 24" single wall stove pipe
Section 3 - 6" dia 24" single wall stove pipe
Section 2 - 6" dia 90° elbow
Section 1 - Adaptor
Radiant Stove

FIGURE 2 STOVE-CHIMNEY SET UP

## RESULTS

All moisture contents were determined on a wet basis. The beetle-killed pine, samples from trees that had been dead approximately ten months as a result of beetle infestation, had an average moisture content of 24 percent. The green pine was the wettest wood tested; it had an average moisture content of 46 percent. The seasoned hardwood had been stored outside for approximately 1 1/2 years. It had the lowest moisture content, 14 percent. The green hardwood samples averaged 30 percent moisture.

Table 1 summarizes the test results. A total of 1545 lbm of beetle-killed pine was burned. This produced 3.61 lbm of creosote with a typical tar-like appearance. The green pine, because of its high moisture content, was difficult to start, but once a bed of coals was established, an adequate fire could be maintained. Two thousand ninety-six lbm of green pine were burned during the test, and this produced 1.81 lbm of a powdery textured creosote. The seasoned hardwood produced 3.84 lbm of creosote from 2079 lbm of wood, and 2484 lbm of green hardwood produced 3.22 lbm of creosote. The creosote produced by both the wet and seasoned hardwoods had a typical sticky, tar-like consistency.

Table 2 compares the creosote accumulation per unit of wood consumed on a wet basis and a dry basis. Both means of comparison show that the beetle-killed pine produced the largest accumulation of creosote. The beetle-killed pine was followed by the seasoned hardwood in creosote production. The green woods produced lesser amounts of creosote; the green pine produced the smallest amount of any of the test woods.

Figure 3 shows the variation of creosote accumulation versus moisture content for the tests run. The drier woods produced more creosote than did the wetter woods. A comparison of the sectional accumulation is shown in Table 3. As expected, the creosote accumulation was much greater in the lower, single wall stove pipe sections than in the upper insulated chimney sections. The green pine produced the least creosote of any of the woods. These results of this study agree with studies at AWL and at the University of Wisconsin [4]. Figure 4 shows AWL results in terms of the Creosote Number for four series of tests that compared the creosote production for different types of woods in different types of stoves. The Creosote Number [1 and 3] is a relative comparison of the amount of creosote production; the Creosote Number increases with creosote production. Note that in these results it is the type of appliance that is the significant parameter. That is, the degree of air tightness and the means of controlling the combustion air supply to the stove are more important than the type or moisture content of the wood.

TABLE 1 SUMMARY OF CREOSOTE TEST RESULTS

| Wood Type | Mass of Fuel (Wood and Moisture) Consumed (lbm) | Mass of Creosote Accumulated (lbm) | Average Flue Gas Temperature $^{o}$F | Average Moisture Content % (Wet Basis) |
|---|---|---|---|---|
| Beetle-Pine | 1545 | 3.61 | 317 | 24.74 |
| Green Pine | 2096 | 1.81 | 317 | 46.14 |
| Seasoned Hardwood | 2079 | 3.84 | 313 | 13.54 |
| Green Hardwood | 2484 | 3.22 | 317 | 30.43 |

TABLE 2 CREOSOTE ACCUMULATION PER MASS OF WOOD

| Wood Type | Mass of Creosote Accumulated (lbm) | Mass of Fuel (Wood and Moisture) Consumed (lbm) * | Mass of Dry Wood Consumed (lbm) | lbm Creosote ton fuel | lbm Creosote ton dry wood |
|---|---|---|---|---|---|
| Beetle-Pine | 3.61 | 1545 | 1163 | 4.67 | 6.21 |
| Seasoned Hardwood | 3.84 | 2079 | 1798 | 3.69 | 4.27 |
| Green Hardwood | 3.72 | 2484 | 1728 | 2.59 | 3.73 |
| Green Pine | 1.81 | 2096 | 1129 | 1.73 | 3.21 |

TABLE 3 Sectional Comparison of Creosote Accumulation in Stove Pipe and Chimney

| Section* | Beetle Pine | Green Pine | Seasoned Hardwood | Green Hardwood | |
|---|---|---|---|---|---|
| 1 | .1063 | .0542 | .0836 | .0591 | Adapter |
| 2 | .1846 | .1409 | .1960 | .2035 | 90° Elbow |
| 3 | .7369 | .3766 | .7217 | .6066 | 24 inch sections of single wall stove pipe |
| 4 | .7689 | .3191 | .7385 | .6141 | |
| 5 | .6659 | .3012 | .7301 | .5978 | |
| 6 | .1535 | .0600 | .1629 | .1314 | Double wall roof support |
| 7 | .3230 | .1286 | .4648 | .3034 | 30 inch sections of double wall insulated chimney pipe |
| 8 | .2972 | .1358 | .2944 | .2600 | |
| 9 | .3762 | .2911 | .4441 | .4401 | chimney cap |

*Section Numbers correspond to Figure 2

Creosote Accumulations in lbm

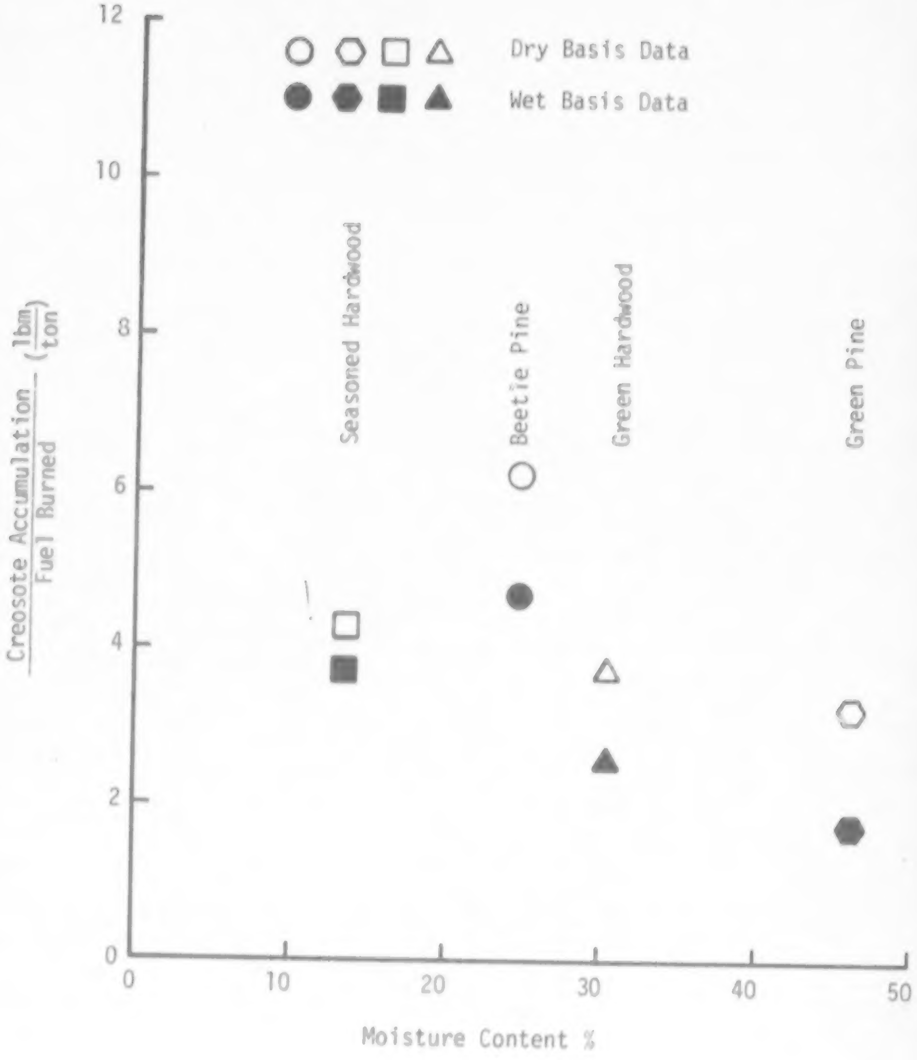


Figure 3 Creosote Accumulation vs Moisture Content

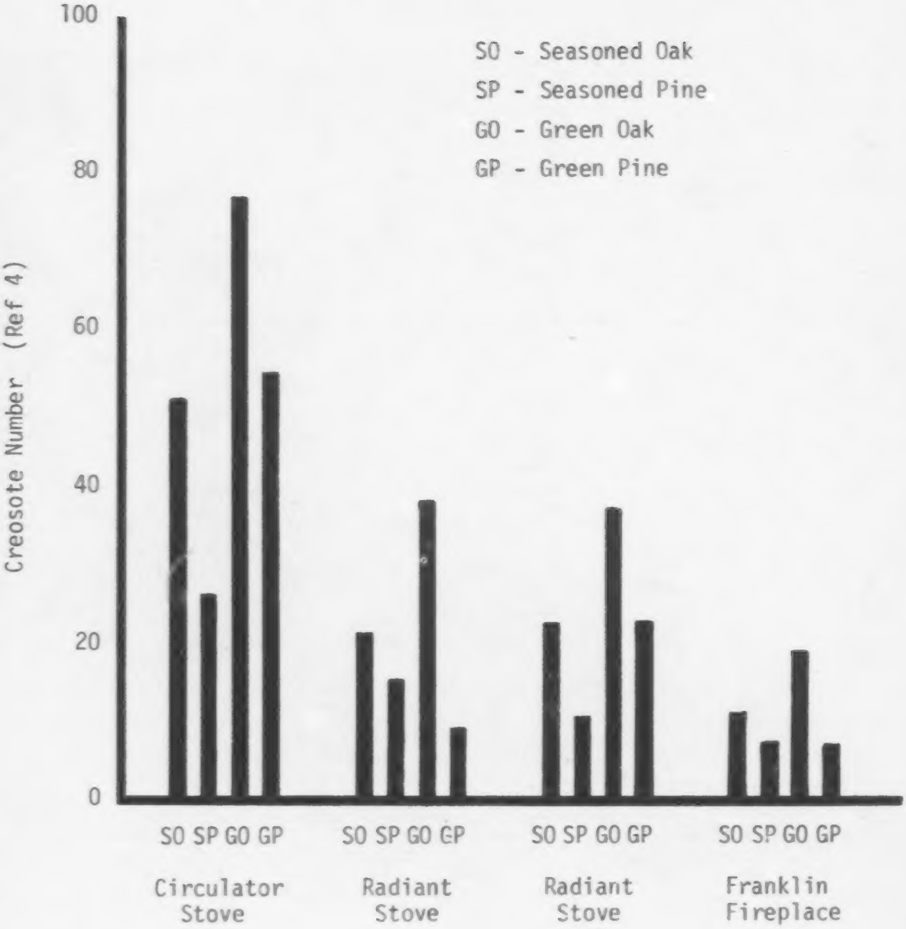


FIGURE 4 Creosote Numbers For Different Type Appliances (Ref 4)

## CONCLUSIONS

All of the woods tested produced significant amounts of creosote accumulation. The woods with the lower moisture contents produced the largest amounts of creosote accumulation. This agrees with the results reported by others, Maxwell et al [1, 3] and Jorstad [4].

The beetle-killed wood produced more creosote than did the other woods. However, all of the woods produced significant amounts of creosote. Thus, beetle-killed pine should not be rejected as a fuel wood on the basis of creosote production.

Based on the relative creosote production, green pine would be the best choice for fuel wood. However, many parameters should be considered when obtaining fuel wood. On a dry basis there is little difference in the energy content per pound of different species of wood; but because pine is much less dense than most hardwoods, the volume of pine required to produce a given amount of heat will be greater than that of oak or hickory. This also means that a full charge of pine will not burn as long as a full charge of hardwood. The two parameters that most likely determine the source of fuel wood a homeowner selects are cost and availability. Beetle-killed pine should have an advantage over hardwoods with respect to cost.

All things considered, seasoned hardwoods are probably the best choice for fuel wood. However, as noted earlier, the demand for fuel wood is growing, and thus the large amount of beetle-killed pine cannot be overlooked. Beetle-killed pine cannot be rejected as a source of fuel wood for wood burning stoves because of creosote accumulation. This study and others show creosote accumulation is relatively unaffected by the species and moisture content of the wood burned. In fact, the only real factor is the amount of air provided to the combustion process, the type of appliance and the air inlet settings. Any type wood can be burned without undue creosote accumulation if the appliance is operated with sufficient combustion air.

*Flue gas temperatures were recorded and air inlets adjusted to maintain temperature between 300-350°F.*

Finally, two warnings are in order. The chimney of any wood burning appliance should be of adequate construction; single wall stove pipe is not a chimney. A regular chimney maintenance should be established. This program should include periodic inspections of the chimney and flue and cleaning when necessary. Also, caution should be exercised when cutting dead standing timber. Dead limbs can fall out and the top of the tree can break out and fall. There should always be someone to watch for these dangers while the tree is being felled.

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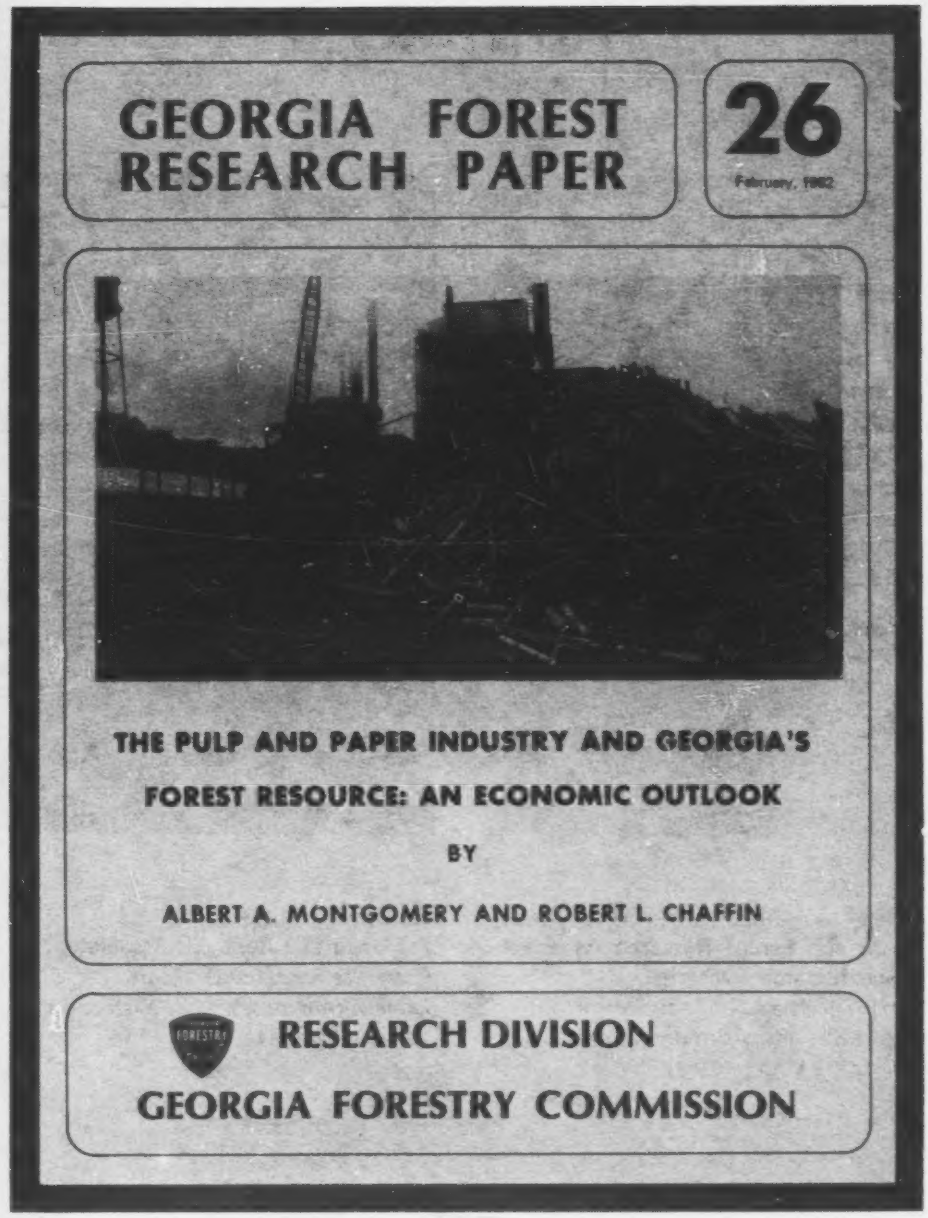

# GEORGIA FOREST RESEARCH PAPER

26

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# THE PULP AND PAPER INDUSTRY AND GEORGIA'S FOREST RESOURCE: AN ECONOMIC OUTLOOK

BY

ALBERT A. MONTGOMERY AND ROBERT L. CHAFFIN

RESEARCH DIVISION
GEORGIA FORESTRY COMMISSION

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# THE PULP AND PAPER INDUSTRY AND GEORGIA'S FOREST RESOURCE: AN ECONOMIC OUTLOOK

PREPARED FOR
GEORGIA FORESTRY COMMISSION

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# HIGHLIGHTS

Georgia is the nation's leading producer of woodpulp and paper and paperboard products, and leads the south in shipments of converted products.

Georgia's pulp paper and allied products industry is comprised of 168 plants, employing 27,000 workers at wages 40 percent higher than paid all manufacturing employees in the state.

Georgia's 16 primary pulp mills have a pulping capacity of 16,457 tpd, up from 13,778 tpd in 1970. These mills are clustered in the Coastal Plain Region.

Georgia's paper and board industry consists of 28 mills with an output capacity exceeding 16,000 tpd. Integrated mills produce daily 15,200 tons of pulp and 14,600 tons of paper and board products. Nonintegrated paper and board mills produce about 1,000 tons of products daily.

Georgia's pulp and paper mills exhibit economies of scale that are incomparable with the competition in any region of the world. The Georgia industry claims seven mills with a pulping capacity of 1,000 or more tons per day. These mills have a replacement cost estimated at $300 million per 1,000 tpd of capacity.

Georgia's paper and paperboard converting industries consist of 124 plants, located mostly in metropolitan areas.

Georgia's dominance in world class mills is underpinned by the rapidly growing southern pine forest. Location economies dictates the siting of large mills close to the requisite wood supplies. The doubling of pine growth through improved forestry management will halve the wood supply areas of existing mills and shorten wood hauling distances by 30 percent.

Georgia's pulp, paper and board industries are dependent on nonindustrial forest lands for about 60 percent of present and future wood requirements. In turn, investment in expanded mill capacity is linked to investments by nonindustrial landowners in the future productivity of timberland.

Georgia's commercial forest can economically supply 909.5 million cubic feet of pine annually on a sustained yield basis at the average stumpage price of $335/MCF prevailing in 1977. Based on current wood demands and the feasible long-run supply of pine, the Georgia forest can support additional pulping capacity of 2,000 tpd. A future stumpage price of $350/MCF would generate a wood supply capable of supporting 2,600 tpd in expanded mill capacity.

Georgia's forest resource is capable of wood productivity gains of at least 10 percent, through restocking with superior seedlings and scheduled timber management improvements. At current stumpage prices of $335/MCF this more productive Georgia forest would support expanded mill capacity of 5,300 tpd, along with proportionate increases in the state's sawmills and plywood mills. This addition of 1.9 million tons annually to the state's pulp and paper mill capacity would generate $1.6 billion in industry investment and create 5,000 additional high paying jobs. National and international markets can readily absorb all the incremental pulp production that a managed more productive Georgia forest can sustain.

# INTRODUCTION

This study evaluates the future of Georgia's pulp, paper, and board industries and the state's forest resource. The analysis focuses on the vital relationships between wood supply, improved forest management, and the potential expansions of mill capacity. The determinants of the future wood supply available to the industry are interpreted. Future markets for the products of Georgia's pulp, paper, and board industries are assessed. Most importantly, scenarios are developed to show how forest investment today can lead to the realization of long-run industry expansion potentials.

The most significant resource constraint upon the continued growth of Georgia's pulp and paper industry is the future pine timber supply. Continued industry investments in plant modernization and expansion indeed depends upon investments being made today by landowners in the regeneration and improved future productivity of the forest. At the rate at which forest management is currently accomplished by Georgia's nonindustrial landowners, it is problematical whether the future pine timber supply will support further industry expansion, even though the existing forest may be able to supply an expanded capacity for a time.

Realistically, far more investment in improved forest management may be currently economically feasible than is being accomplished by nonindustrial landowners. In turn, these investments will assure a future timber supply that would enable Georgia's pulp and paper industry to eventually expand its capacity by as much as 1.9 million tons annually beyond the 6.1 million ton annually already in place or coming on line in the immediate future.

# ECONOMIC CHARACTERISTICS OF GEORGIA'S PULP, PAPER AND BOARD INDUSTRIES

The principal reason for the exceptional growth of the pulp and paper industry in Georgia is the unique affinity between this industry and the southern pine forest. In turn, the industry's potential for further economic growth depends in particular on the improved management of the southern pine forest as a renewable, multiple product, economic resource. But there are a number of other economic resource considerations which have affected this industry's growth, if not giving it a special economic advantage in Georgia and the South, and which stand as potential constraints on its future growth.

## LABOR AND WAGES

In 1978, the average earnings of Georgia's paper and allied employees was $6.99 hourly, compared with a wage level of $6.52 an hour for workers in this industry throughout the United States. Moreover, the wages paid this industry's employees exceeded the wages paid to all Georgia manufacturing employees by more than 40 percent. The high wages of the paper and allied products industry reflects the high productivity of its employees, due not only to their exceptional skills but to the highly capital-intensive nature of the industry. At these premium wage rates, as justified by the industry's high productivity, an abundant supply of labor is available to accomodate any foreseeable level of industry expansion.

At the same time, these high wages and the implied high production value added per employee signify that the growth of this industry contributes much more to Georgia's economy than indicated by the number of its employees. Even so, paper and allied products ranks as Georgia's ninth and the Atlanta metropolitan area's sixth leading manufacturing employer; and its employment growth has been steady, if not spectacular. The industry employed 25,060 in 1970, 26,200 in 1974, and 27,000 in 1978 and is projected to grow to 29,530 in 1985.

## WATER

Water is an essential, high-use resource in the manufacture of pulp, paper, and board products. A pulp and paper mill producing 1,000 tons of output per day may use as much water as the population of a city of one million. Although the quantity of water used in the manufacture of pulp and paper varies widely depending on the pulping process, this resource is a necessary input at every stage in the manufacture of pulp.

At the time of this study, water consumption data were available for seven mills which produced 9,165 tons of pulp daily. The combined water requirements of these seven mills was almost 200 million gallons per day. Even with these large gallonages, Georgia mills are highly efficient in minimizing water requirements through the reuse of water withdrawn for manufacturing processes. Gallons of water used per ton of output ranged from a high of 48,000 down to a low of 3,125, depending on the type mill and the pulping process used.

The water requirements of Georgia mills are satisfied by withdrawals from wells and rivers and by purchase. Among the Georgia mills studied the most frequently used sources of water are captive wells and a combination of wells and river water. Based on processes characteristic of existing Georgia mills, an average net withdrawal of 21,800 gallons of water is required for each ton of pulp produced, apparently much less than the national average.

Water availability is not viewed as being a significant limitation on the location of new or the expansion of existing pulp, paper, and board mills in Georgia.Ground or river water supply considerations do, however, limit the choice of locations for future mill sites. Further, the cost of adequate water purification systems to meet effluent limitations guidelines will continue to be a major cost consideration in determining the economic feasibility of capacity additions.

## ENVIRONMENTAL CONSTRAINTS

In real terms, the pulp and paper industry has been more extensively impacted by air, water, and solid waste pollution abatement regulations than most classifications of manufacturers. Between 1973 and 1978 total new plant and equipment expenditures by the pulp and paper industry ranged between 5.0 and 6.6 percent of capital spending by all manufacturing firms. Over this same period pollution abatement spending by the pulp and paper sector was equivalent to between 8.4 and 13.4 percent of abatement expenditures by all manufacturers. The year-to-year fluctuations in pollution control spending are influenced by government deadlines for compliance with pollution abatement standards.

Capital spending to meet pollution abatement standards represents a real cost to the pulp and paper industry that, for the most part, neither expands capacity nor increases productivity. The expenditures mandated to meet environmental standards alone increased the prices of paper products by an estimated 5.5 percent between 1975 and 1978. Irrespective of their merits, mandated standards do cause product costs to rise and can result in the closure of marginal high cost mills. Further, compliance with environmental standards increases the capital cost of new and expanded mill capacity. In constructing a 1,000 tpd pulping facility it is estimated that capital expenditures to meet EPA environmental regulations will represent 12 percent of total mill costs.

For its part, Georgia's industry has programmed $112.1 million in capital expenditures over the 1979-81 period for environmental enhancement, $69.8 million for water and $42.3 million for air pollution control. These expenditures for pollution abatement represent 13.5 percent of all programmed capital expenditures for Georgia mills, as compared with 9.9 percent of total capital expenditures nationally.

If these large investments in environmental protection and the uncertainty of future governmental standards seem daunting for the growth prospects of the Georgia pulp and paper industry, it should be kept in mind that the environmental constraint applies generally to the industry in the Nation and World. Insomuch as industry growth in Georgia and the South is advantaged by other factors, environmental costs will not be an important limitation, per se. Rather, the economic impact of these costs will fall most heavily on competing regions, where mills are less efficient and of marginal profitability.

## ENERGY

The pulp and paper industry is energy intensive. Each ton of output from a pulp and paper mill requires about 35 million Btu's of energy. Thus, a 1,000 ton pulp and paper mill uses each day the energy equivalent, alternatively, of 5,600 barrels of oil, 1,300 tons of coal, 34 million cubic feet of natural gas, or 4,000 tons of bark or wood.

Confronted with rapidly rising energy costs and with the threat of interruption of purchased fuels and electricity, the pulp and paper industry has made substantial efforts both to conserve energy and to lessen its dependence on purchased energy. The use of hogged fuel derived from wood residues by the U.S. pulp and paper industry increased from 5.5 million in 1972 to 12 million tons in 1978. In consequence, the share of the industry's energy requirements accounted for by self-generation with wood residues increased to 45 percent in 1978 from 41 percent in 1972. Concurrently, the industry's use of fossil fuel and purchased energy declined by 16 percent.

Following this national trend, Georgia's industry has been investing in fossil fuel conservation and in-plant generating facilities. Based on data from 13 major Georgia pulp mills, representing 92 percent of the state's pulp output, the Georgia industry is nearly 60 percent self-sufficient in electrical generation. Thus, over the long run, the availability of energy, per se, would not appear to be an important constraint on the industry's expansion. By the same token, the Georgia industry would not appear to be at a regional disadvantage even if the cost of energy continues to rise in the face of industry's investments in conservation and self-sufficiency.

### CAPITAL INVESTMENT

Georgia's pulp and paper industry enjoys no material regional advantage or disadvantage with respect to the availability of water, environmental, energy, and labor inputs. The industry does benefit from two distinct locational assets: the forest resource and the concentration of its productive capacity in large world class mills.

The Georgia pulp and paper industry is incomparable with its competition in any region of the world in that nowhere else is there concentrated in a comparable area so many of the world's largest pulp mills. The state has no less than seven mills with a pulping capacity of 1,000 or more tons per day, including two mills larger than 2,000 tons per day. Equally important, Georgia pioneered world class pulp and paper mills. Except for periodic modernization, expansion, and annual two-week shutdowns for maintenance, some of these large Georgia mills have been operating continuously, 24 hours a day, for five decades. This history of operating success has yet to be matched by the newer large mills in locations outside of Georgia.

The economies of scale enjoyed by Georgia's pulp and paper mills give the industry an important regional economic advantage over the typically smaller mills of the competition. The economic advantage of a large mill is that the required volume of resource inputs into the pulp making process does not increase in proportion to the size of the mill. A 1,000 tpd mill may require no greater number of production workers than a mill producing one-third its output. Thus, the large mill will have lower labor costs per ton of output. Similarly, a large mill will have lower energy costs per ton because of large-scale boiler economies and the economies of large settling ponds and air pollutant precipitators.

In order to recover the enormous capital costs associated with a large efficient mill (estimated at about $300 million per 1,000 tpd of capacity), the production facility must be run continuously for as long as possible. The longer the time period over which the mill can be operated, the lower the capital costs per ton of output. This is because the costs of maintenance, modernization, and expansion at an existing mill will be less than for "green" mill capacity in new locations.

Moreover, the prospect of a mill remaining indefinitely at a fixed site enables it to be profitably integrated with related economic activities. It will be recalled that the Georgia industry is highly integrated not only between pulp mills and paper and board mills, but vertically through the production of converted paper and board products. Georgia mills also evidence horizontal integration between pulp making, the production of wood chemicals, and lumber products. Integration enables the sharing of capital costs and enhances the profitability of an array of forest products.

Finally, there is the advantage of integrative economies that are external in the industry, particularly if there is a cluster of large mills in the vicinity. Given long operating periods at fixed sites, an industry comprised of large mills will attract industry suppliers and other support activities, enhancing capital recovery and economic returns over the long run. This support includes, importantly, the public and private investments necessary to develop the forest resource base of the industry.

## REGIONAL STUMPAGE PRICES AND FOREST MANAGEMENT

The pulp, paper, and board industries in Georgia enjoy real wood cost advantages, despite higher pulpwood stumpage prices, especially in the Coastal Plain Region. Lower wood costs at the mill are attributable to economies associated with year-round harvesting, mechanized logging operations, an extensive transportation network, the high specific gravity of the southern pine, and the rapid annual growth of the pine forest.

From seedlings to pulpwood size in 15 years and sawtimber size in 30 to 35 years, the rapidly growing southern pine forest can sustain a large volume of annual timber supply close to the mill. These distinct wood cost advantages underlie the location and long history of successful operations by world class pulp mills in Georgia. In turn, the sustained pulpwood productivity of Georgia's pine forest has made possible a high degree of industrial integration between pulp mills, paper and board mills, and converted products plants in the state.

### PULPWOOD

The nonindustrial landowner in the Coastal Plain is assured of a future pulpwood market because of the large industry capacity in place. In contrast, the future demand for pulpwood stumpage in the Piedmont Region is not expected to approach that of the Coastal Plain until there is a significant expansion of mill capacity in the region. It is a fundamental economic principle that the pulpwood stumpage price decreases as the distance from the mill increases, because of the incremental cost of transporting wood to the mill.

This principle is illustrated by the data on pulpwood stumpage prices by region in 1977:

PULPWOOD STUMPAGE PRICE

| Region | MCF | Cord |
|---|---|---|
| Coastal Plain | $211 | $20 |
| Piedmont | 168 | 16 |
| Mountain | 100 | 9 |

These stumpage price differentials are directly related to the accessibility of wood to existing mills. At the same time, the mill-delivered pulpwood prices vary but slightly between the three regions, averaging about $350/MCF or $33 per cord.

Because of lower pulpwood stumpage prices and higher acre costs of site preparation and planting, nonindustrial landowners in the Piedmont have been more reluctant to practice improved forest management. The 1977 plantation costs pertinent to nonindustrial lands were $87 per acre in the Piedmont and $77 per acre in the Coastal Plain. These market facts do not imply, however, that investment in site preparation and planting is economically unfeasible for the Piedmont landowner. Over a pulpwood rotation a planted stand in the Piedmont will yield twice the harvestable timber volume of an unmanaged stand. Indeed, in the absence of improved forest management investment, cutover pine timberland will likely revert to virtually useless hardwoods.

### SAWTIMBER

Considering regional variations in management costs and stumpage prices, it is probably not economically feasible to manage the Georgia pine forest under a pulpwood rotation regime. Under current market conditions it is feasible, however, to manage the pine forest in a multiple product context, including sawtimber and plywood logs as well as pulpwood. This is indicated by the price of sawtimber pine stumpage in 1977:

| Region | Sawtimber Stumpage Price per MCF |
|---|---|
| Coastal Region | $614 |
| Piedmont | 464 |
| Mountain | 313 |

On the average, then, sawtimber stumpage is priced at about three times the receipts from pulpwood stumpage.

Multiple product cutting has a large impact on the economics of pine forest management in Georgia. Assume a pine forest mix of 40 percent sawtimber and 60 percent pulpwood, and wood volume of 1,000 cubic feet per acre. The timber sales proceeds from cutting this multiple product forest would be $286 per acre, compared with $168 from a pulpwood rotation. In turn, the investment in site preparation and planting to assure future wood supplies would require but 34 percent of the multiple product timber sales proceeds, as compared with a 58 percent requirement from a pulpwood cutting.

Georgia's pulp, paper, and board industries will benefit from the multiple-product management of the state's pine forest. The higher return to the landowners will accelerate forest management practices and enhance total wood supplies. A part of industry's pulp roundwood needs will be available because of the value of thinning as a sawtimber management practice. Notwithstanding longer hauling distances, the flow of chips and residues as sawmill and plywood byproducts can be delivered to pulp mills as cheaply as pulp roundwood.

### FOREST MANAGEMENT AND THE LOCATION OF PULP MILLS

The economics of locating and sustaining pulping capacity dictate that mills be sited close to the requisite wood supplies. Indeed, the margin for profit is small in the assembly and hauling wood to the mill. The value adding characteristics of the industry are accomplished by large reductions in the weight and bulk of the wood fiber input. A ton of pulp weighs less than one-fourth of the wood input. In turn, the finished pulp is valued at more than 13 times the stumpage value of the pulpwood used in its manufacture.

Improved forest management is critical in renewing the wood requirements of Georgia's pulp mills. The managed pine forest can assure continuing wood cost advantages to Georgia mills by locating the wood resource nearer to the industry's large mills.

### PULP MILL WOOD SUPPLY AREAS

The relationship between pine forest management and the economics of mill location are depicted on Map 1. The common points for the concentric circles represent existing mill sites, except for the cluster of mills along the Georgia coast. In determining the pulp mill wood supply areas it was assumed that the indicated daily pulping capacity was operated 350 days per year and that 1.25 cords of wood are processed to produce one ton of pulp output. It was further assumed that 57 percent of the pine growth volume was harvested as pulpwood and 43 percent as sawtimber. In turn, about 30 percent of the sawtimber harvest is available to pulp mills as sawmill chips and residues.

The inner supply circle illustrates the shortened mill logging distance under a plantation management regime that harvests 1.0 cord per acre per year. The outer supply circle encompasses the land area required to supply indicated mill capacity assuming an unmanaged pine forest yielding an annual harvest of .5 of a cord per acre per year.

This wood logistical illustration shows that a doubling of pine growth through forest management would halve the wood supply areas of existing mills and reduce wood hauling distances by almost 30 percent. As a corollary implication, improved forest management makes it possible to log a larger more economically viable mill at competitive wood costs with a much smaller mill.

### EFFECTS OF SHORTENED WOOD-HAUL DISTANCES ON INDUSTRY EXPANSION

The wood-haul shortening effects of forest management on the economic growth of the industry in Georgia are profound. Existing mills can expand pulping capacities without increasing the average distance of wood hauls and, thus, without incurring rising wood costs per ton of output for an increasing volume of wood supply. If existing mills do not expand capacity to utilize fully the increased productivity of the pine forest, opportunities are created for the location of new mills at the extremities of existing wood supply areas.

A significant expansion of mill capacity and Georgia's forestry economy is dependent on the future supply of wood from lands at the extremities of the wood supply areas of existing mill sites. In truth, the inclusion of all industrial and nonindustrial pine land in the Coastal Plain under sustained yield, plantation management would not provide sufficient wood to log permanently the existing pulp mill capacity in the region. The expansion of pulping capacity in Georgia, then, is dependent on investment by nonindustrial landowners located at considerable distances from existing mills, especially in the Piedmont Region of the state.

### INDUSTRY OWNED AND LEASED FOREST LAND

Industry owns or holds under long-term lease about 3.5 million acres of pine land in Georgia. The goal of a sustained yield, even-age management on this industry acreage has been about two-thirds realized and can be accomplished within a decade.

Industry owned acreage alone, however, does not assure Georgia mills of a future wood supply. Pulp and paper companies are managing increasingly their woodlands on longer sawtimber rotations. This is an outgrowth of the accelerating integration of pulp, paper, and board mill operations with lumber, plywood and other forest products plants. In light of these development patterns, industry lands are capable of supplying only about 40 percent of the existing wood fiber requirements of Georgia mills.

Georgia's pulp, paper, and board industries are dependent, then, on nonindustrial forest lands for about 60 percent of present and future wood inputs. In turn, investment in expanded mill capacity is linked inextricably to investments by nonindustrial landowners in the future productivity of their timberland.

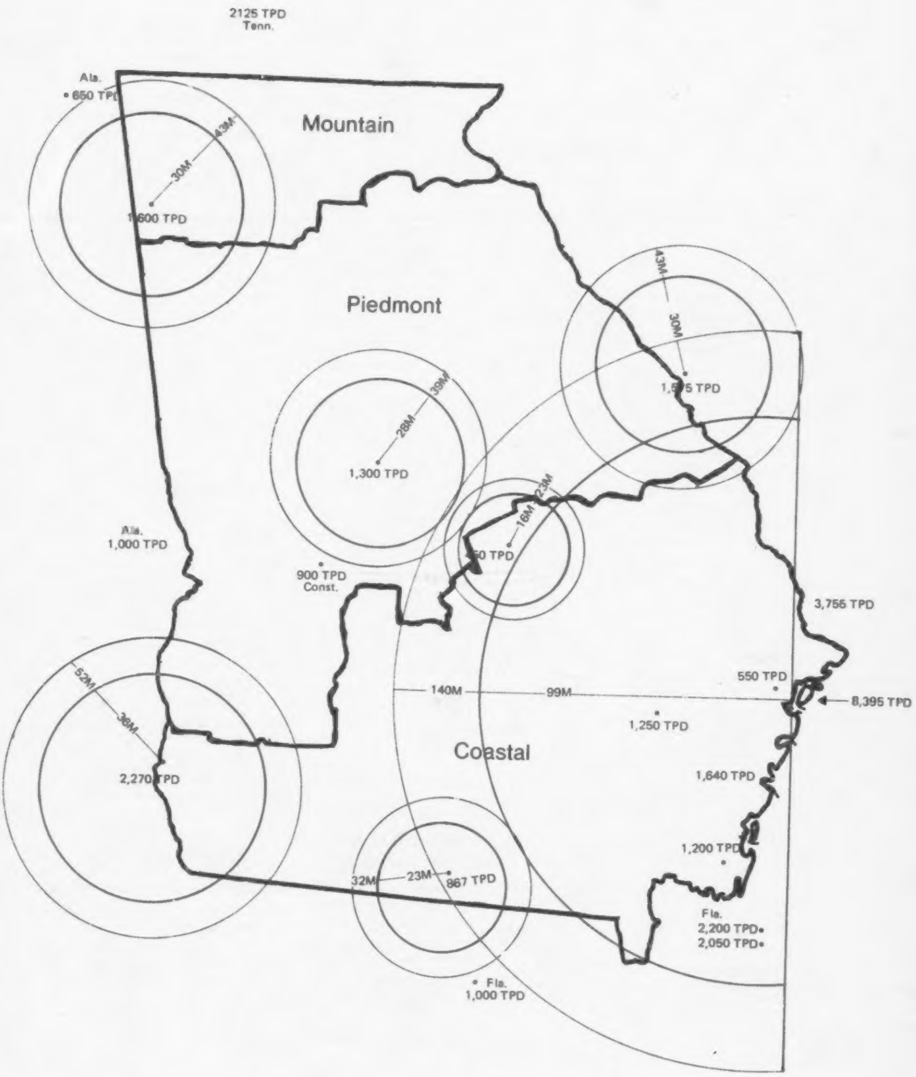
## DETERMINANTS OF THE FUTURE WOOD SUPPLY

The pulp, paper, and board industries are wood resource dependent. Because of the ownership distribution of the forest land resource, the future of these leading Georgia industries hinges on whether nonindustrial landowners expand the wood supply through forest management. The variables that will determine future wood supply include:

1. The expected stumpage price.
2. The current costs of forest management. Management costs include site preparation, planting, and other forest practices. The alternatives to plantation management are natural stand forest management.

Map 1

## Hypothetical Pulp Mill Wood Supply Areas



3. The rate of interest or capital cost imputed to forest management costs. Capital cost will differ by public, industry, and nonindustrial land ownership classifications.
4. The ad valorem property tax applicable to private forest lands.
5. The timber yield from pulpwood thinnings and final harvest. In turn, yields will vary by the choice of rotation lengths and management plans applied to timberlands lying in various forest types, productivity and physiographic classes, regions, and ownerships.
6. The availability of land for pine forest management in each geographic region of the state. The availability of land is dependent on existing conditions of operability and accessibility, existing forest types, and the loss of timberland to competing land uses.

Indeed, the large number of factors determining the economic potential for profitably managing Georgia's forest resource are so complex that it was necessary to utilize the "Computer Model of the Long-Run Timber Market and Forest Management" developed for Georgia by the Contract Research Division of the College of Business Administration at Georgia State University.

## LONG-RUN PINE TIMBER SUPPLY CURVE AND THE STUMPAGE PRICE LEVEL

### CURVE $S_1$

Georgia's long-run supply curve for pine timber projected by the model takes the positive slope of the classic supply curve. As shown in Figure 1, the annual volume of pine forest growth that can be supplied to the stumpage market in the future at an acceptable profit to landowners is greater as the stumpage price rises.

At a real price level equal to the 1977 average stumpage price of $335/MCF, it is economically feasible for landowners to supply 909.5 million cubic feet of pine annually on a sustained yield basis. This long-run pine supply potential compares with 687.4 million cubic feet of pine volume removed for all industrial uses in 1971, the year of the last Forest Survey. At 1977 management costs and stumpage prices, it is feasible to make current investments in cutover timber land that will ultimately yield 222.1 million cubic feet of additional pine volume over that removed in 1971.

What do these summary data mean in terms of the availability of wood to support expanded mill capacity? In 1971, the pulp and paper industry in Georgia consumed an estimated 479 million cubic feet of wood, equal to 70 percent of pine roundwood removals in the state. The supply of pine was augmented by 62.5 million cubic feet of hardwoods. Since 1971, however, the pulping capacity of Georgia mills has increased from 13,880 tpd in 1971 to 16,457 tpd currently. Further, a new mill with a pulping capacity of 900 tpd is under construction. Since 1971, the pulping capacities of Georgia mills has increased a substantial 25 percent. An analysis of current wood demands by Georgia mills and the feasible long-run supply of pine, considering current forest management costs, stumpage prices, and mill delivered prices, indicates that the Georgia forest can support additional pulping capacity of only 2,000 tpd.

However, the positive slope of the long-run timber supply curve means that a rise in the real stumpage price will bring forth a larger supply. If the future stumpage price rises to a level of $350/MCF it becomes economically feasible to manage Georgia's pine forest for a 937.5 million cubic feet pine supply. This sustained level of wood supply is capable of supporting about 2,600 tpd in expanded mill capacity. At higher stumpage prices the supply curve becomes increasingly inelastic, meaning that the pine supply required to support larger pulp mill capacities would require sharply higher delivered wood costs for all forest products industries in Georgia.

### CURVE $S_2$

Supply curve $S_2$ is the result of a second run of the model for this study. It differs from supply curve $S_1$ only in that it assumes pine plantation yields rise by 10 percent, a wood productivity gain that should be realizable through restocking with superior seedlings and scheduled timber management improvements. Representing an increase in supply, $S_2$ lies to the right of $S_1$. Further, supply curve $S_2$ indicates that it is economically justified to manage the pine forest to supply greater volumes of sustained yield at all prospective levels of stumpage prices.

At the current price level of $335-MCF, an annual pine supply of 1.07 billion cubic feet is feasible under the $S_2$ assumption. This supply level exceeds that which is feasible at current prices under the lower plantation yield assumption of supply curve $S_1$ by 164.7 million cubic feet. The added volume of pine supply available at the current price level under supply curve $S_2$ would support an expansion of mill capacity by 5,300 tpd, as well as proportionate increases in the capacities of the state's sawmills and plywood mills.

The data generated by the model showing the sustained annual pine timber supplies under $S_1$ and $S_2$ management practices at varying stumpage price levels are presented in Table 1. The timberland management prescriptions that would make feasible the $S_1$ and $S_2$ long-run curves are described in the unabridged study.

Table 1

GEORGIA'S LONG-RUN PINE TIMBER SUPPLY
(Constant 1977 Dollars)

| Stumpage Price Level $/MCF | Sustained Annual Yield Supply 1 M Cu.Ft. | Supply 2 M Cu.Ft. |
|---|---|---|
| 50.00 | 356.7 | 356.7 |
| 100.00 | 356.7 | 356.7 |
| 150.00 | 40636.8 | 41656.6 |
| 200.00 | 253651.8 | 278641.8 |
| 250.00 | 355896.1 | 419418.6 |
| 300.00 | 744994.6 | 910432.6 |
| 335.00 | 909453.9 | 1074191.0 |
| ----------------Current Price Level---------------- | | |
| 350.00 | 937498.3 | 1086042.0 |
| 400.00 | 1017136.4 | 1148199.0 |
| 450.00 | 1078549.0 | 1201772.0 |
| 500.00 | 1112335.0 | 1290636.0 |
| 550.00 | 1135843.0 | 1341085.0 |

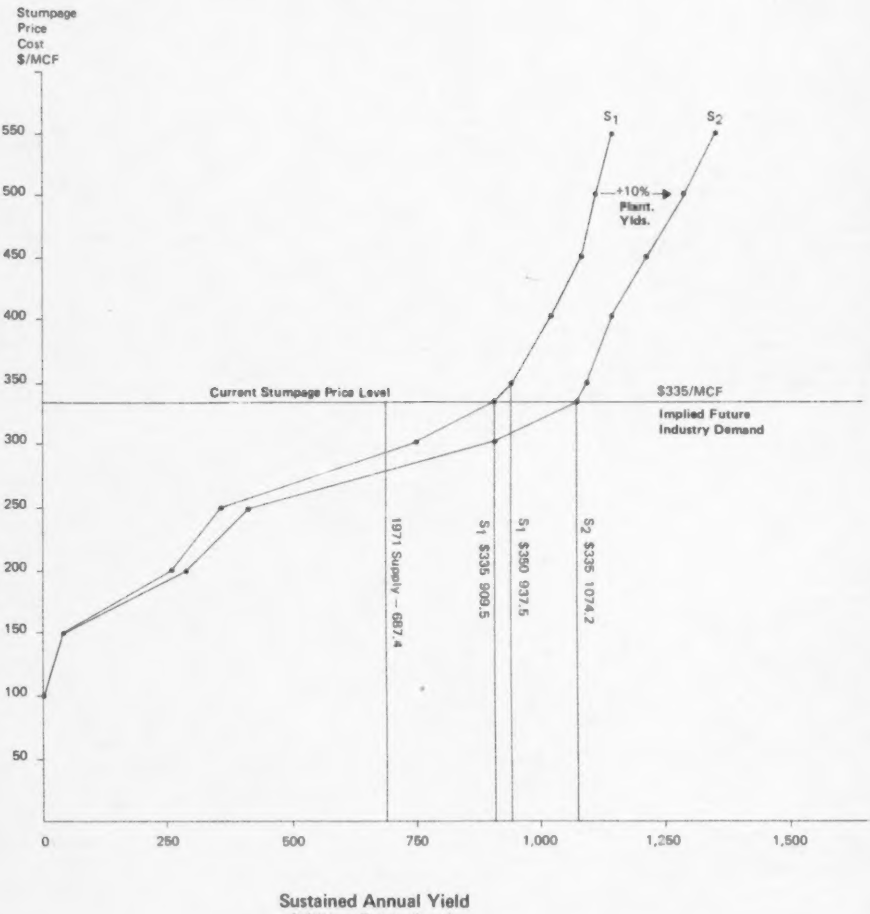
Source: Economic Model from Southeast Forest: An Economic Outlook, Montgomery, Robinson, and Strange.

## INDUSTRY AND STATE BENEFITS FROM INCREASED TIMBERLAND PRODUCTIVITY

The economic benefits accruing from the increased productivity of the Georgia forest are substantial. The employment and income gains flowing from the primary industry expansion and the management of the forest resource would help ameliorate rural poverty in Georgia. At present costs it is estimated that the direct expansion of pulp and paper mill capacity entailed by the feasibility of forest management would add 1.9 million tons annually, generate $1.6 billion in industry investment, and create 5,000 additional skilled high paying jobs. Importantly, a large fraction of this potential pulp and paper industry expansion potential can be realized in the near future, provided industry has the assurance that this realizable vision of the future

Figure 1

**Georgia's Future Pine Timber Supply**
**Alternative Economic Outlooks**
(1977 Constant Dollars)



Georgia forest is supported by landowners, state and federal policy makers, and the public.

## FUTURE MARKETS FOR GEORGIA'S PULP, PAPER AND PAPERBOARD PRODUCTS

Georgia's pulp, paper, and board industries serve both national and international markets. While the pulp mills located in the state are integrated extensively with paper and board mills, Georgia produces a significant share of the Nation's market pulp supply.

### PULP IMPORTS

The United States imported 4.1 million short tons of pulp in 1979. While these imports constituted 7.7 percent of the total pulp supply available for domestic use, imports represented 57.6 percent of the new market pulp supply. Based on the realization of a mill expansion potential of 1.9 million tons of woodpulp per year, Georgia produced pulp could substitute for 46 percent of current national imports if all potential increased production were marketed nationally. It should be noted that domestic converters and specialty mills are especially dependent on pulp imports and would constitute a primary market for expanded production by Georgia mills.

### PULP EXPORTS

In 1979, the United States exported 2.7 million short tons of pulp. Were the entire 1.9 million tons of Georgia's pulp expansion capacity exported it would increase the Nation's current pulp exports by 70 percent. Even if, as today, relatively little of the expanded Georgia output were to be sold as market pulp, the greater production would help to narrow the Nation's trade deficit in woodpulp. In 1979, this excess of market pulp imports over exports amounted to 1.4 million short tons.

### FUTURE MARKETS FOR THE PRODUCTS OF GEORGIA MILLS

The products of Georgia's pulp, paper, and board industries have significant market penetrations in virtually every activity associated with the industrial, commercial, governmental, and household sectors of the economy. Consequently, the change in constant dollar gross national product is conventionally used as a surrogate in projecting the demand for paper and paperboard products.

Between 1967 and 1973, the national consumption of paper and board products maintained a relationship at about 53,700 tons per billion dollars of real GNP. Since 1973, the United States has experienced a slowing of growth in constant dollar GNP. In turn, a downward shift has taken place in the relationship between paper and paperboard consumption and the level of real economic activity to about 50,100 tons per billion dollars of GNP. Nevertheless, the annual consumption of paper and paperboard products in the United States exceeds 600 pounds per capita, which is the highest standard in the world.

This apparent weakening in the level of national demand for paper and board products in relation to economic activity is, in part, related to the rapid rise in the market price for woodpulp. Since 1967 this price has more than tripled, with the price index standing at 322.5 in September 1979. The inflation in the price of wood pulp is, in turn, symptomatic of increasing cost pressures confronting the industry nationally and internationally.

These trends bode well for the expansion of the pulping capacities of Georgia mills. The rising price of woodpulp is an economic signal that capacity should be expanded in regions where pulp can be manufactured profitably at the market price.

Georgia mills enjoy a pulp manufacturing cost advantage due to the scale economies of world class mills and the wood cost advantages of the southern pine forest. These pulp cost advantages, in turn, bestow distinct economies on the production of paper and board products by Georgia mills. Coupling these locational assets and cost advantages with an expanded future timber supply, Georgia mills can enhance their dominant position in the manufacture of pulp, paper, and paperboard products, and thus greatly increase the dollar value of the industry to the state economy.

## STRUCTURE AND CAPACITIES OF THE PULP, PAPER AND BOARD INDUSTRIES IN GEORGIA

Comprised of 168 plants, the pulp, paper, and allied products industry in Georgia is broadly diversified. Georgia ranks first among the nine states that claim an annual woodpulp production capacity in excess of 2.5 million tons. Considering the annual capacity to produce paper and paperboard products, Georgia again claims first position among the 14 states with output in excess of 2.5 million tons yearly. Georgia holds top position among southern states in shipments of converted products and ranks among the ten leading states nationally. Georgia is thus positioned as the nation's largest and most extensively integrated producer in the pulp, paper, and allied products industry.

### PULP MILLS

The pulping capacity of Georgia's 16 primary pulp mills stood at 16,457 tons per day in 1978, up from a total of 13,778 tons per day in 1970. This pulping capacity is largely concentrated in the sulfate or kraft process, as follows:

PULP PRODUCTION BY PROCESS IN GEORGIA, 1978

| Process | Production Tons per Day | Distribution |
|---|---|---|
| Total Production | 16,457 | 100.0% |
| Sulfate (Kraft) | 13,927 | 84.6 |
| Groundwood/ Mechanical | 1,750 | 10.6 |
| Semi-Chemical | 780 | 4.8 |

Between 1970 and 1979 Georgia mills added 2,679 tons of daily pulping capacity. These capacity additions were concentrated 64.8 percent in the sulfate (kraft) process.

An examination of the pulping processes employed by Georgia mills indicates that 12 mills produce pulp using a single process and four mills manufacture pulp by more than one process. The following processes are used by the 16 primary pulp mills located in Georgia:

PULPING PROCESSES USED BY GEORGIA MILLS, 1970

| Process | Number of Mills |
|---|---|
| Single Process: | |
| Sulfate | 8 |
| Groundwood/Mechanical | 3 |
| Semi-Chemical | 1 |
| Multiple-Processes: | |
| Groundwood/Mechanical --Sulfate | 1 |
| Sulfate --Semi-Chemical | 2 |
| Thermomechanical-Recycled Newsprint | 1 |

A well-defined geographical pattern has emerged in the location of Georgia's pulp mills and the associated paper and board mills. As is generally characteristic of capital intensive firms producing a product (wood pulp) from relatively low value, high weight inputs (pulpwood), pulp mills have located close to wood sources. Additionally, pulp mills in Georgia are typically integrated with a primary paper and board mill. Because of the economies of scale inherent in mill integration, the geographical location of paper and board capacity is similar to that of pulping capacity. Converting plants that fabricate paper and board into industrial and consumer products tend to cluster in manufacturing centers and are more geographically dispersed.

The geographical location of Georgia's primary mills by daily tonnage is presented on Map 2. As illustrated, pulp mills are clustered in the coastal counties and in the Coastal Plain Region of Georgia. Chatham County leads the state with four mills which have a combined pulping capacity of well over 3,000 tons per day. As shown on the map, one additional pulp mill is currently under construction in Macon County.

Georgia pulp mills are typically very large, world class mills, as illustrated by the following distribution of the daily pulping capacities of individual mills:

| Pulping Capacity (Tons per Day) | Number of Mills |
|---|---|
| 2,000 and over | 2 |
| 1,000 to 1,999 | 5 |
| 500 to 999 | 4 |
| Under 500 | 5 |

This pronounced tendency toward large mills is an outgrowth of the economies inherent in expanding mill capacity at existing sites and in product and process integration.

In 1980, the manufacture of wood pulp in Georgia celebrated a golden anniversary. The first of today's primary mills was located in Chatham County in 1930. During the 1930's, an additional three mills located in Georgia's coastal counties. These four mills dating from the 1930's have a current output capacity of 4,695 tons per day. The 1940's witnessed the addition of four new mills which now have a combined capacity to produce 3,200 tons of pulp per day. The decade of the 1950's ushered in three more mills with a current capacity of 3,717 tons per day. The 1960's was a significant growth period in which four "green" mills were added that now produce 4,395 tons per day.

During the late 1970's one additional mill was completed and another was under construction that will have a combined initial production capacity of 1,350 tons per day. It was typical in Georgia during the decade of the 1970's that significant capacity additions arose from investment in mill modernization and the addition of onsite capacity at existing mills. As an example, the Great Southern Paper Company in Cedar Springs, Georgia, completed a $25 million investment in mill upgrading in 1978 that increased the output of unbleached kraft linerboard and corrugating medium by 300 tons per day.

## PAPER AND BOARD MILLS

Georgia's paper and board industry consists of 28 firms, 15 of which are integrated pulp, paper, and board mills. The paper and board industry has an output capacity exceeding 16,000 tons per day. This capacity is concentrated in the integrated pulp, paper, and board mills, which represent more than 90 percent of total capacity.

The geographical dispersion of Georgia's 21 leading paper and board mills by tons per day of capacity is presented on Map 3. Paper and board mills in Georgia are typically large scale, capital intensive operations, as illustrated by the following distribution of production capacities.

| Paper and Board Capacity (Tons per Day) | Number of Mills |
|---|---|
| 2,000 and over | 2 |
| 1,000 to 1,999 | 3 |
| 500 to 999 | 6 |
| Under 500 | 10 |

All paper and board mills in Georgia that are not integrated with a pulp mill have a daily production capacity of under 500 tons. These mills have clustered in metropolitan areas since World War II and typically serve a regional market. The scale of employment in unintegrated mills is substantially less than is generally found in integrated pulp, paper, and board mills.

Using a combined industry classification, the county location of employment in Georgia's pulp, paper, and board mills is depicted on Map 4. Because of the widespread integration of paper and board mills with pulp mills, employment is concentrated in those counties with an established wood pulping capacity.

Georgia's integrated mills currently produce daily an estimated 15,200 tons of pulp and 14,600 tons of paper and board products. The nonintegrated pulp mills produce an estimated 1,250 tons of pulp daily, and the nonintegrated paper and board mills in Georgia produce 44 major classifications of products. Certain of these products enter final markets, while others provide inputs to manufactured products by converted paper products plants and container and box plants.

## CONVERTING PLANTS

The paper and paperboard converting industries in Georgia represent a complex structure of 60 converted paper and paperboard products plants, 62 paperboard container and box plants, and 23 plants that manufacture both converted and other paper and allied industry products. Specifically, Georgia plants manufacturing converted paper and paperboard products produce 42 standard products and paperboard container and box plants produce 17 product classifications.

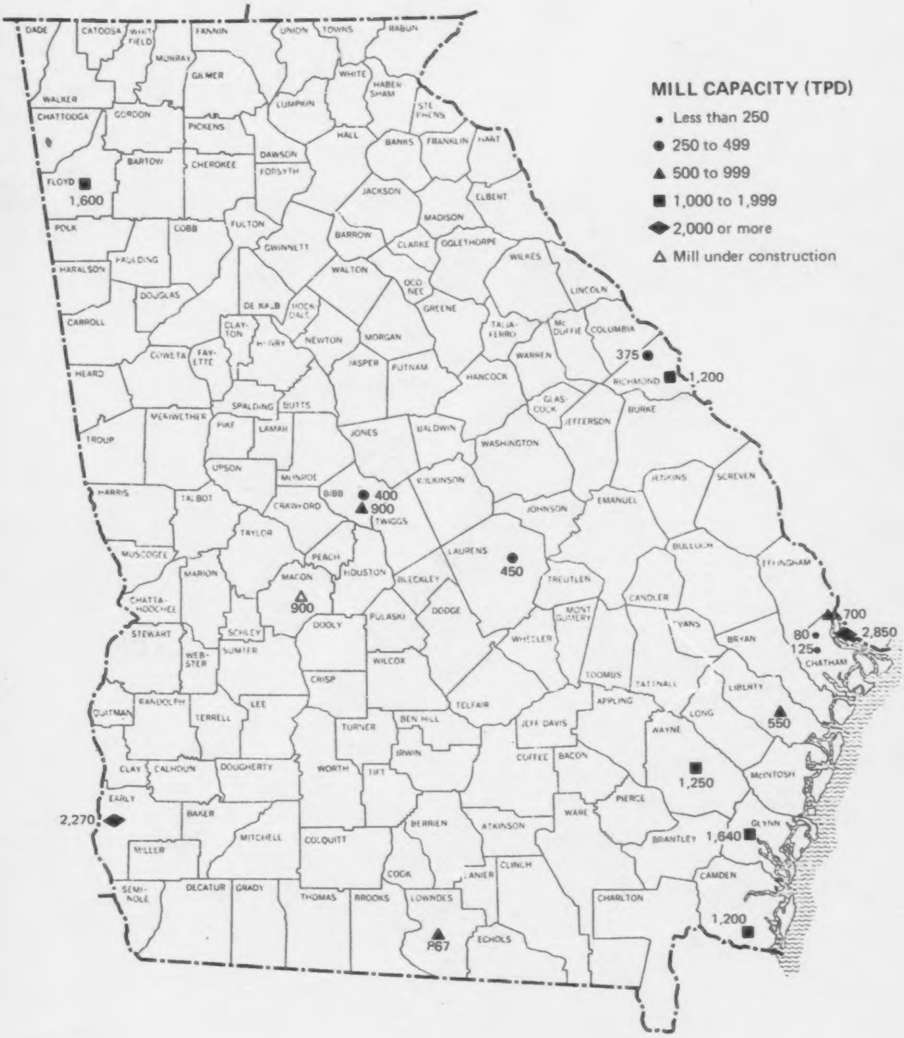
The distribution of employment in converted paper and paperboard plants by county is presented on Map 5. A few counties with very limited employment and usually a single plant are not included to avoid disclosure. Employment in the converting industries is markedly concentrated in metropolitan areas. It is noteworthy that 22 firms in this industry classification are located in Atlanta and five are situated in Macon.

The distribution of paperboard container and box plants is more diffused geographically than the scatter of converted paper and paperboard plants. This is illustrated in the location of the 18 Georgia counties with significant employment in the industry, as shown on Map 6. Interestingly, nine of the counties with significant employment in the container and box industry are dually listed as having significant employment in the converted paper and paperboard industry. Again, a pronounced urban location tendency is illustrated by the container and box industry, since proximity to industrial customers is a meaningful location determinant.

## Map 2

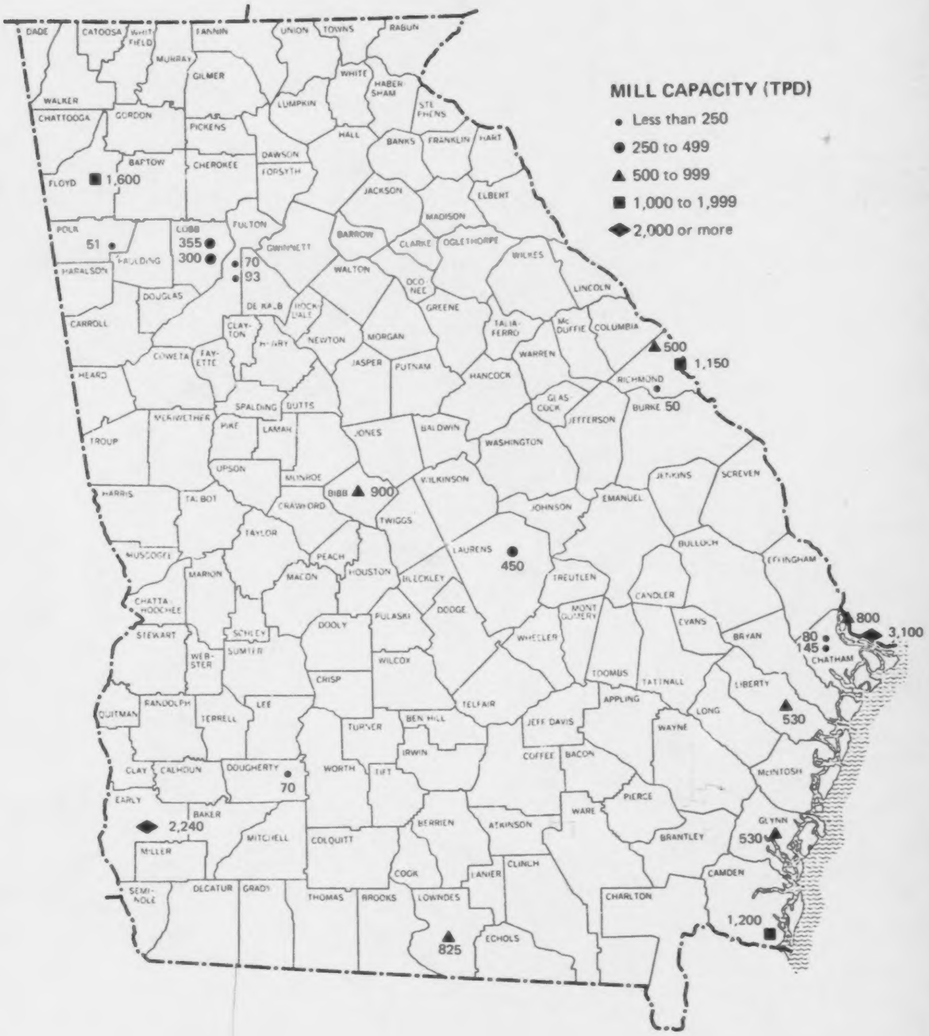
## Georgia Pulp Mill Production Capacities

(Tons Per Day)



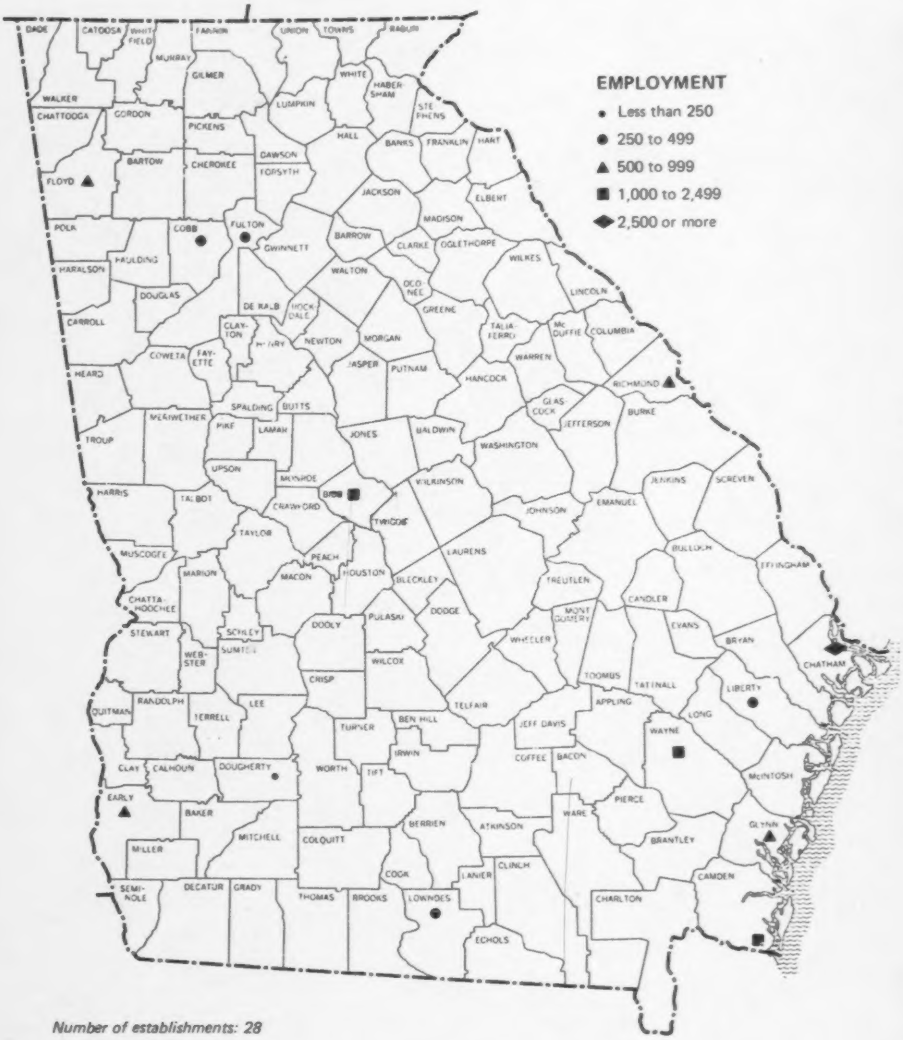
Map 3

## Georgia Paper and Board Mill Production Capacities
(Tons Per Day)



Map 4

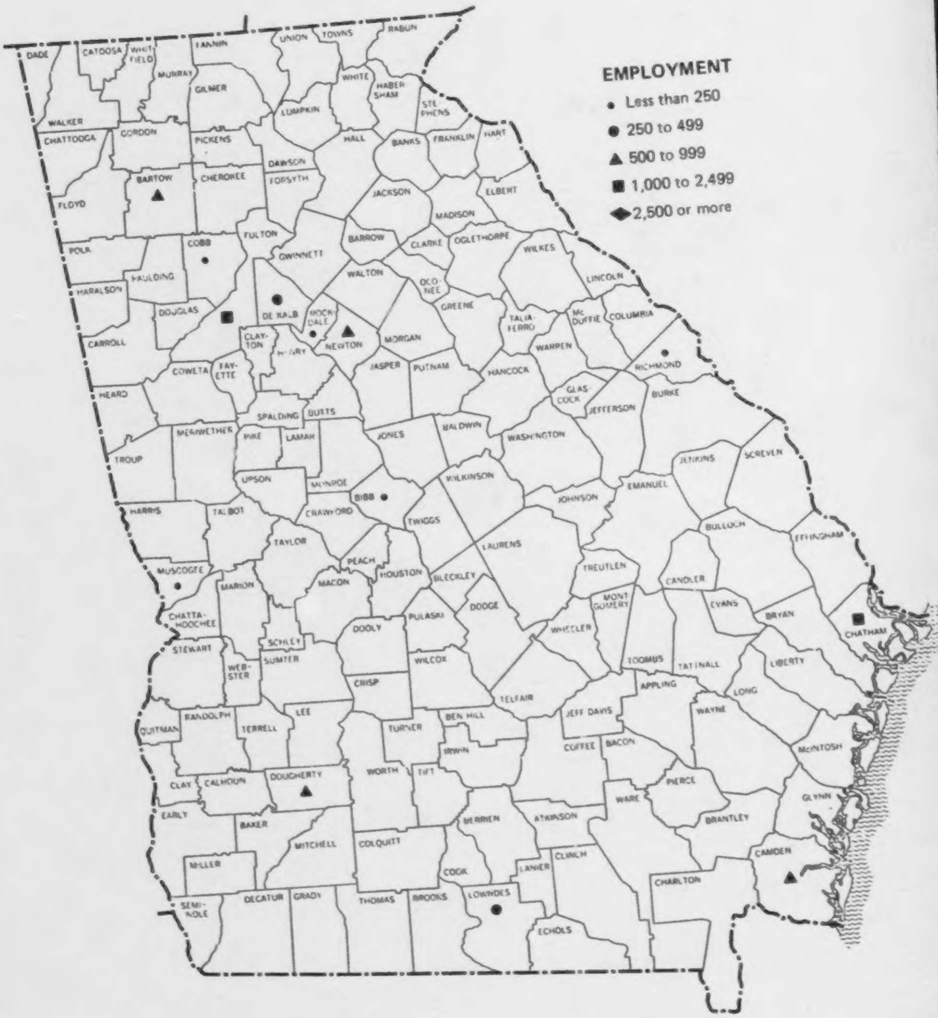
## Georgia Employment In Pulp, Paper, And Board Mills
(By County)



*Number of establishments: 28*

Map 5

## Georgia Employment In Converted Paper And Paperboard Products
(By County)

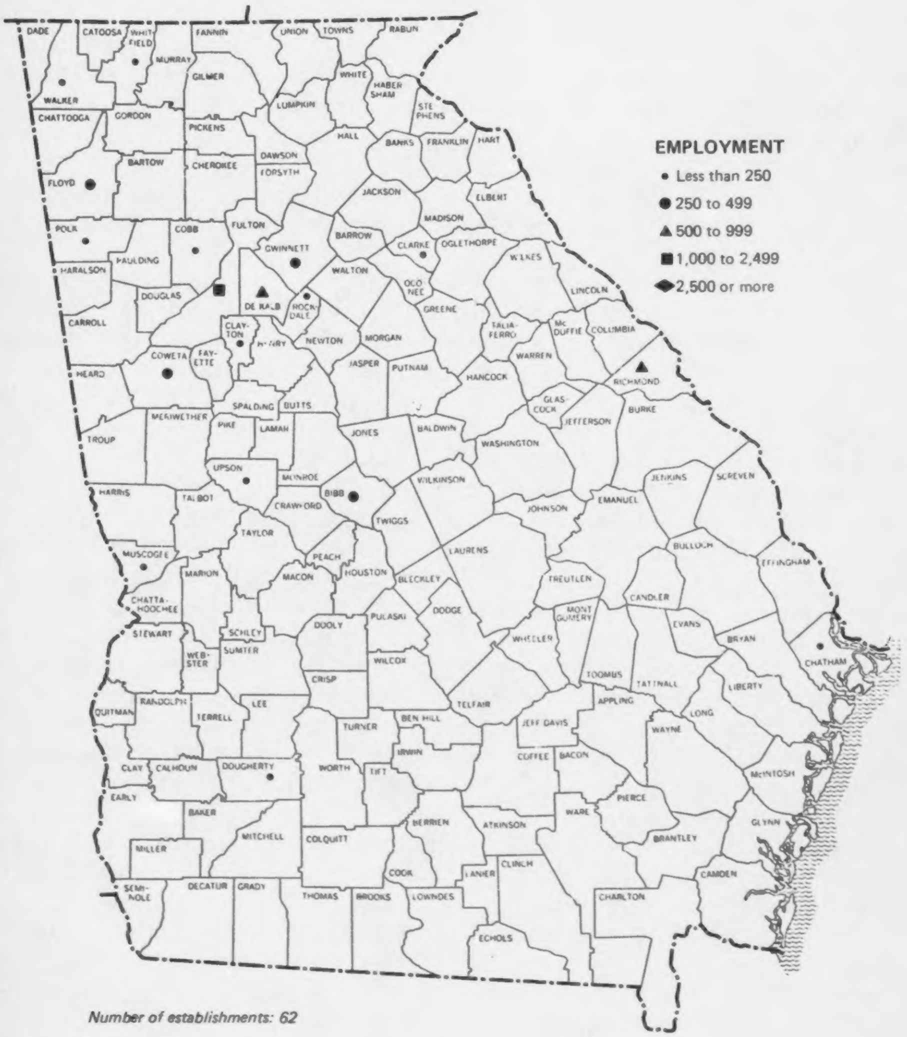


*Number of establishments: 60*

MAP 6

## Georgia Employment In Paperboard Container And Box Plants

(By County)



*Number of establishments: 62*

Mr. HEITOWIT. Thank you very much, Mr. Shirley.

We next have with us Dr. Wayne Smith, director of the center for biomass energy systems and for environmental and natural resources programs, University of Florida Institute of Food and Agricultural Sciences.

Mr. SMITH. Thank you, Mr. Chairman. My name is Wayne Smith. I am director of the environmental natural resources systems, biomass energy systems. We are pleased to be here to talk to this committee about the research and development needs program for the 1980's.

The subject you have chosen, I think, is very timely. The oil supply situation called a glut by many allows us the breathing room to plan our need for research and development without the cloud of a crisis.

Now I have tried, in my written testimony, to lay out the program of research and development that I believe can significantly impact energy in the 1980's with a renewable component—biomass.

What I want to do at this time, at your suggestion, is to summarize my comments just to highlight the points that I tried to make in the written statement testimony. The written testimony will stand for the record if that is still agreeable.

The first point that I want to make is that the energy mix for the future is going to be very diverse. We do not think it is going to be possible anymore to allow a single source of energy to meet all needs as we have in the past. We went through wood, then coal, and then oil. We also believe that in the future, biomass, particularly in the southeastern United States and my own State of Florida, can make a signficant contributuion. But we must get on with the research and development needs to make that a reality and we think that it is possible by a well-conceived and well-planned program. I tried to outline such a program in the written testimony.

Now, I might just highlight the two basic premises that I use for developing that statement.

We have made a good start using waste and residues, but for a sustainable biomass and biofuels industry, we have to develop feedstocks for energy purposes.

We, and the land grant university system's experiment stations, have spent about a century developing the food, feed, and fiber crops that we now have. I think we have wasted a lot of time over the fuel versus food argument. We don't expect cotton to be a good food crop nor do we expect tomato to be a good fiber crop, so we should not expect these food and fiber crops to be energy crops. If we are to have energy crops, we have to develop them using the same scientific principles that were used to develop the crops we now grow.

In my testimony, we have outlined the steps that you go through in developing crops for energy purposes just as we did to develop them as our food fiber sources.

Now, in essence, we are talking about screening, determining how to culture, and then how to improve them genetically.

The analogy I would like to make is that we have gasoline because we have crude oil, not because we have refineries. We will have a sustainable biofuel, petrochemicals industry when we have something analogous to crude oil and that is called plant feedstock and we can develop them using good science.

The next point I want to make is that the conversion technologies we have are similarly inadequate. The ones that we are now using, and we are doing a pretty good job using them, were, by and large, developed for other purposes, in other words, for waste disposal and for the spirits industry. They were not developed for the energy industry. We feel that advancements in those technologies also can be made through a well-conceived and well-executed research program. I have tried to identify some opportunities for that in my testimony.

In developing bioenergy, we are going to have to use some very conventional technologies, but we think we also have the opportunity today to use some very contemporary biotechnologies that haven't been available to use in the past. In that regard I am talking about protoplasm, fusion, tissue culture, recombinant DNA technologies, using these where we can make quantum jumps in biotechnology in a reasonable time and get on with developing energy crops and converting the biomass to useful forms.

In the written testimony that I prepared for you, I have tried to lay out an agenda for research in the 1980's that would make renewable energy from biomass a significant part of our energy mix for the future. Members of the land grant university system, such as my University of Florida, have a long record of successful research in the development of new crops and using them for food, feed, and fiber. The extension arm of this system has proven to be highly effective in demonstrating and disseminating the new advances to the agricultural, industrial, and public sectors. The system stands ready to assist in all ways possible and to participate in a program of research, development, and demonstration to help provide Americans with renewable energy sources.

We are hopeful, however, that the Federal Government will respond to this need and to this opportunity to use the resources of the States by providing the support necessary for the research, development, and demonstration efforts as required.

Mr. Chairman, I appreciate the opportunity to appear here and to prepare the comments for the record and the opportunity to participate in the panel discussion.

Thank you very much.

[The prepared statement of Wayne Smith follows:]

# TESTIMONY FOR BIOMASS PANEL
# SUBCOMMITTEE ON ENERGY DEVELOPMENT AND APPLICATIONS OF THE SCIENCE AND TECHNOLOGY COMMITTEE

MAY 28, 1982
KNOXVILLE, TENNESSEE

Field Hearing on "Renewable Energy in the Eighties: Needs for Further Research, Development and Demonstration"

My name is Wayne Smith. I am Director of the Centers for Biomass Energy Systems and for Environmental and Natural Resources Programs of the University of Florida's Institute of Food and Agricultural Sciences. Both of these Centers have programmatic concerns with energy. I wish to address you today on biomass and its development for "renewable energy in the eighties".

The subject you have chosen could not be more timely. The oil supply situation (called a "glut" by some) allows breathing room for us to plan our needs for further research, development, and demonstration without the cloud of crisis. Such planning and new programs must be launched because we know fossil energy supplies will become increasingly limiting for geologic, economic or political reasons. Thus, it is a matter of time before oil supplies become limiting and prices surge again as they did in the seventies.

Developing renewable supplies and demonstrating applicable technology will help lessen the requirement for spending dollars abroad to purchase oil. Perhaps the current favorable supply situation will last long enough for research to develop the new needed technologies. Conservation has gone about as far as it can go; off-the-shelf renewable technology is now on-the-ground and in some cases contributing about all that can be expected. The pressing need is for new technologies, which are possible only through well-conceived, innovative research, development, and demonstration programs.

The energy mix for the future will be diverse with contributions coming from a variety of sources. Since single energy sources such as wood in earlier times, coal in the late 1800's, and oil in the 1900's do not appear possible, we can no longer discount energy sources that can only supply a portion of the total demand. Biomass—plant matter that stores solar energy as chemical energy—is one of the renewables showing potential for contributing to an energy mix for the future. Estimates vary as to the potential for biomass but recent assessments place the U.S. potential between 4 and 15 quads (or even up to 35 quads under crisis conditions) by the year 2000, at which time the total projected demand will be 80-110 quads. While the exact contribution is yet to be determined, it is clear that biomass can make a significant contribution. For this potential to be realized, research must be done on biomass production and conversion so that useful energy forms can be developed in economically, energetically and environmentally sound ways.

In the Southeast, including my State of Florida, we are in a favored location for developing biomass energy because we have the climate, land, water, and a variety of adapted plants. The urgency for developing renewable energy sources for our region is underscored by a growing consumptive demand with only small supplies of liquid and gaseous fossil sources. While biomass energy appears especially suited to our region, we recognize that elsewhere other renewables (wind, geothermal, OTEC, solar, etc.) may be the preferred source and that biomass will not be the only renewable energy useful in this region. Hence, we encourage concurrent development of all feasible renewable sources.

Some success has been possible to date in commercializing biomass energy production using available technology. Further development is constrained mainly because these efforts made use of surplus food crops and their by-products, wastes and other residues as feedstocks and made use of conversion technology developed for the spirits and chemicals industries. While a start can be made using these feedstocks and available conversion processes, a sustainable industry must await the development of energy crops and advancements in conversion technology.

First, let us consider energy crop development. These crops must meet certain criteria:

1. Provide a year-round feedstock supply through sequential availability of seasonal crops or through storage;
2. Comprise plant constituents that are convertible to energy-dense chemicals; and
3. Possess a favorable energy ratio and balance to produce significant quantities of energy per acre with a low investment of production energy.

Many of the crops we currently grow were developed by the Experiment Stations at the Land Grant Universities. These developments took advantage of information accrued on plant genetics, on physiology and nutrition, on crop ecology, and on pest and farm management technologies. Because these crops were developed for food/feed/fiber, we should not expect them to be good energy crops. For example, corn is an excellent food/feed crop that possesses an energy ratio of just over 1.0 (i.e. the final energy available barely exceeds the energy used to produce the crop). For energy it is not a good crop. Thus, crops must be developed using the same scientific principles that gave us our food/feed/fiber crops, and we should not get distracted with the food vs fuel arguments before the crops are developed. We should not get into oranges vs apples comparison.

Energy crop development does not have to await the centuries of development that we have had for other crops. We have the scientific information that evolved over the decades available to us, so with appropriate support we should be able to move deliberately and rapidly. A first step is to determine plant species fulfilling the above criteria that can grow in each environmental niche. For example, we have identified about 100 species for Florida that show potential as energy crops. Many of these plants are presently classed as weeds (Henry David Thoreau defined a weed as a plant whose virtues are unknown). The strategy for utilizing such plants is to take advantage of their capacity to produce abundant biomass without requiring abundant management energy. For example, aquatic plants such as water hyacinth (a weed problem in many lakes and canals) will produce about 50 tons per acre of dry biomass per year if nutrient enriched wastewaters (sewage effluent, farmland drainage water, etc.) are available. Similarly, napiergrass (or elephant grass), a weed in Florida cane fields, but an abundant biomass producer, may prove to be a good energy crop. Among woody plants in our state, the "weed-tree" melaleuca may prove to be a good energy crop--its bark contains energy-dense (highly flammable) chemicals and it will grow at an early age in thick stands (maximizing photosynthetic energy capture). Preliminary estimates suggest that the energy ratios for these crops will be 5.0 or more (recall, corn is just over 1.0). To develop energy crops, the research steps may be identified as follows:

1. Screen species for their local and regional adaptability and potential to produce abundant biomass;
2. Identify genetic variability within each new energy crop candidate (noting ranges in growth rate, pest resistance, chemical composition, and sensitivity to environmental stresses);

3. Determine cropping strategies by determining optimum plant density, planting dates, harvesting period and frequency, and cultural inputs to maximize energy yield per unit area, time, and invested energy;
4. Assay the plant products for their convertibility to useful energy forms; and
5. Initiate a breeding program to genetically improve the plant species for energy cropping purposes.

Another biomass research focus should be on pretreatment requirements to transform plant biomass into useful chemical feedstocks. For example, lignocellulosic wastes (waste wood, cane bagasse, food fibers) presently are our most abundant and reliably available biomass feedstocks (e.g. in Florida it is estimated that over 20 million dry tons per year are available). Also, woody biomass crops are showing very favorable energy ratios when grown in energy plantation configurations. A restraint is their convertibility. Research areas that need to be expanded include:

1. Development of low energy harvesting, drying, and size reduction procedures to prepare lignocelluloses for conversion;
2. Advancement of enzymatic procedures for converting cellulose to fermentable sugars by improving cellulase enzyme production and by accelerating the reactions that lead to fermentable glucose; and
3. Advancement of physico-chemical treatments of lignocelluloses to achieve the separation of cellulose from lignin and to facilitate their conversion to useable chemical feedstocks.

Assuming successful development of energy crops and the systems to grow them, improved processes must be developed through research to efficiently convert the biomass to useful energy forms. This is especially true for biological conversions to alcohol or methane. Despite centuries of experience with fermentation, the technology is not well suited to energy production. For example, a fundamental problem in alcohol fermentation is the inability of the microorganisms involved to tolerate stress conditions (or conditions that would improve process efficiency) such as increased concentrations of alcohol or elevated temperatures in the fermenting matrix. Presently the ethanol producing yeasts retain their viability in alcohol concentrations of about 9-10 percent when temperatures remain at about 30°C. As temperatures increase, for example, to 37°C, the alcohol tolerance decreases to 6-7 percent. The identification or development of organisms that could withstand increased concentrations and temperatures would reduce the amount of water to be removed from the alcohol (an energy demanding step) and make the process more efficient by allowing the use of vacuum distillation at elevated temperatures. These improvements, coupled with increases in biochemical reaction rates and improved engineering processes, would greatly enhance alcohol production from biomass.

Methane gas production from biomass has been recognized for a long time. While some of the organisms capable of forming methane have been identified, their specific roles and biological requirements for efficiently converting biomass to methane are poorly understood. Anaerobic digesters are plagued with operating problems because the factors controlling the biochemistry of methane formation have not been adequately defined. Intensively focused research could provide this information so that appropriate engineering systems can be designed, fabricated and operated efficiently and economically.

Many advances that can be made must make use of conventional scientific principles; but we are not limited to these. Available to scientists today are the new biotechnologies that could allow us to take quantum steps forward in reasonable time. I am referring to tissue/protoplast culture and recombinant DNA techniques. For example, in energy crop production, a pressing question is "how will the nitrogen be supplied?". We know that using nitrogen fertilizer made from natural gas is not energetically sound. While nitrogen-fixing companion or rotation crops should be used if possible, biotechnology could provide another option: namely, the insertion of the nitrogen fixing genes into the target energy crops.

Protoplast culture techniques provide a vehicle for introducing desirable genes into a single cell and regenerating a plant from that cell. All cells of the regenerated plant would possess the new genes. Fusion of protoplasts from related or unrelated species also provides a new strategy for breeding and selecting for useful variations (such as increased growth rate, pest resistance, content of chemicals easily convertible to useful energy forms). Regardless of plant origin, field propagation (especially in high-density energy farms) represents a problem. Emerging tissue culture techniques coupled with "fluid-seeding" technology may provide a low-cost way to propagate "genetically true" energy crops. Similarly, by inserting genes that impart tolerance to temperature, osmolarity and inhibiting by-products into existing fermentation organisms, we could greatly improve the conversion processes for forming either alcohol or methane.

Developing new biomass feedstocks and the pretreatments for those now available is crucial. An assured supply of renewable energy from biomass will be possible when an economically affordable, reliably available, and efficiently convertible feedstock supply is assured. We have gasoline because we have crude oil--not because we have refineries.

There are other advancements in conversion technology (especially thermochemical gasification) that could be useful to advancing biomass energy, but I will not mention these because others on the panel will address them. However, I believe that I have provided you an agenda for research in the eighties that would make renewable energy from biomass a significant part of our energy future. Members of the Land Grant University System, such as the University of Florida, have a long record of successful research in developing new crops and the technologies to use them for food, feed, and fiber, while protecting our soil and water resources and environmental quality. The Extension arm of this system has proven to be highly effective in demonstrating and disseminating the new advances to agricultural, industrial and public sectors. This system stands ready to assist in all ways possible, and to participate in a program of research, development, and demonstration to help provide Americans with renewable energy sources. We are hopeful that the federal government will respond to this need and to the opportunity to use resources in the states by providing the support necessary for a research, development and demonstration program for renewable energy to help solve this nation's energy problems.

Mr. Chairman, I appreciate this opportunity to address the subcommittee on this important subject.

Mr. **Heitowit**. Thank you very much, Dr. Smith.

We will have a couple of questions from staff.

Mr. **Frankel**. Thank you very much. We have had a number of reports to the Department of Energy or to the Congress that have made recommendations about research needs in the biomass area and I would like to read summaries of them to the three of you and get your feedback on them.

The Office of Technology Assessment Report on Energy from Biological Processes recommended the following areas as the highest priorities for R&D: "Crop development, forest management, gasifiers, ethanol synthesizers, the utilization of methanol and liquid fuels production." Those were the six areas they recommended. Do you have any problems with any of those areas? Do you think those are good areas or did they miss anything?

Mr. **Shirley**. I would like to reply if I might. The gasification program needs further research. I think that it is No. 1 priority. The priorities ought to reflect where you can get the most energy converted to actual use by the public.

We have the wood. All we must have now is a combustion system. We have acceptable direct wood combustion systems. We need more applied research. Right now we have hundreds of plants in Georgia waiting to see what wood system they ought to install to do the job at the lowest price.

Now, we don't have to go out there and research a plantation of trees to see what is best to grow. We have more forest trees growing now than we can sell. We have plenty of raw material to sell. When you harvest hardwood trees, you have coppice for reforestation. We have the raw material suitable for wood energy. What we really need now is to convince the industrial world of this reality.

Mr. **Smith**. I believe if I heard all of those items well, and I am not sure that I did, I don't have much quarrel. I believe the development of energy crops is a high priority and I would certainly endorse that. I think all of them, except perhaps the alcohol production on the farm are priority areas that I can identify with. Farmers do a better job of farming than making alcohol; maybe in this region some of the people did a good job of making alcohol and perhaps distributing it so I think there are people that are experts in that area. But I don't know that I would give that a very high priority for farmers. I think the farmers can produce the feedstocks if we can do the research to develop the crops and the technology to convert them to a variety of gaseous and liquid fuels. I think that would probably be a wiser strategy.

Mr. **Bulpitt**. With regard to two of the categories you were talking about, to get back to the ethanol and methanol production, I believe that you were limiting that to wood. That seemed to be, or at least it was one of OTA reports that I read that was heavy on wood. There are a number of entities around the country that are working on that question and that seems to skirt the question of food versus fuel that the other feedstocks always bring up.

I believe that there is a lot of room for further research in the production of ethanol and methanol from wood. The problem that has been holding this research back right now in a lot of ways is the fact that the alcohol is still more expensive than gasoline alone, but I think we need to figure that someday that is no longer going to be the case.

With regard to gasification, there are a number of programs that DOE is working on right now, particularly in the medium BTU gasification area. We feel that these need to be continued and that there is further need for new areas. The direct substitution of biomass derived gas for natural gas and fuel oil in this country is almost an unlimited possibility given mostly the question of production quality and what you are trying to do with the gas and these are all application questions that can be answered with further research.

Mr. **Steinway**. One technology that the committee has been hearing a great deal of testimony about is the fluidized bed combustion technology. Do you think that the use of biomass as a feedstock with this technology is an approach that we should be considering in the future? Have you done any work in this area and if so, do you have any recommendations for us to take back to Washington?

Mr. **Bulpitt**. I will respond to that.

The area where fluid beds really took off was in coal to begin with, because you were able to use as a bed material limestone and other elements that will help you counteract effects of sulfur that you find in coal.

There are a number of units on the market using wood a fuel now. We have a number of them installed in Georgia at private companies using fluid bed technology.

Personally, I don't see any gross advantages to fluid beds for burning wood over conventional furnaces. If the units are designed right to begin with for direct combustion, it is a tossup to me whether you go for the fluid bed or whether you go for the conventional traveling grate process.

I think this is one area that is mature enough to where the market is just about going to take care of it, particularly in the wood burning field. And, Ray, I know you have had some contact with the fluid beds.

Mr. **Shirley**. Yes, we do have a number of companies that have installed this sytem that are highly complimentary of the success of the fluidized bed. I think it is like any other combustion system. I believe we have had enough research to know what it will do.

Mr. **Hanson**. The Energy Research Advisory Board last year issued a report indicating the need for a greater emphasis on the production of biomass crops rather than conversion. Do you agree with the recommendations of that Board? Do you think we have a good balance in the Department of Energy research program between production and conversion support activities?

Mr. **Shirley**. I would like to answer that because we have made an experiment study on this in conjunction with U.S. Forest Service. They indicate in Georgia, the Southeast, and nationwide no shortage of biomass at this time.

Nor, do we foresee any shortage in the future. The U.S. Forest Service reports that 7 percent of the total energy needs could be met with forest biomass, and in Georgia up to 30 percent of the State needs if we have the demand. The people that have raised this question have not researched it. We made a forest resource study for a company in Georgia that wanted to put in a plant but they were concerned about whether enough biomass material was available to be put in. They have a large plant. We found in a 15-mile radius that they had enough to run continuously and still supply everything else. We normally deal with a 50-mile radius. So there is no problem in the Southeast. So I don't think there is any question in my mind.

The thing I would advise is go to the experts who know what the real facts are throughout the Nation. The State forestry organizations and the U.S. Forest Service will support what I have said.

Mr. **Heftowitt.** Thank you very much for a stimulating panel.

Our last panel consists of Dr. Jack Ranney, director, biomass program, Oak Ridge National Laboratory, and Mr. John Stinson, manager, biomass fuels program, Tennessee Valley Authority in Knoxville.

I understand that John Stinson will be accompanied by one of his colleagues, Charles Buffington, who can respond to any questions that may come up later on.

We will begin with Dr. Ranney. If you could summarize your testimony, we have your full statement for the record and it will be included in its entirety.

## STATEMENT OF J. W. RANNEY, RESEARCH ASSOCIATE, ENVIRONMENTAL SCIENCES DIVISION, OAK RIDGE NATIONAL LABORATORY, OAK RIDGE, TENN.; AND JOHN M. STINSON, MANAGER, BIOMASS FUELS PROGRAM, TENNESSEE VALLEY AUTHORITY, MUSCLE SHOALS, ALA., ACCOMPANIED BY CHARLES D. BUFFINGTON, CHIEF, PLANNING AND PROGRAM DEVELOPMENT, OFFICE OF NATURAL RESOURCES, KNOXVILLE, TENN.

Mr. **Ranney.** Thank you, Mr. Chairman and members of the subcommittee. It is both an honor and a great opportunity for me to appear before you this afternoon.

I am a professional forester and employed at Oak Ridge National Laboratory and I have been field manager for the U.S. Department of Energy's short rotation woody crops program since the beginning of 1978.

In this position I am responsible for the technical guidance of 30 field research projects. This research is located in universities and institutions in all regions of the country that appear capable of supporting short rotation intensive culture.

As the U.S. Representative to the International Energy Agency Working Group on Forest Growth and Production, I am also aware of forest energy research in other countries. Today I am going to talk about the short rotation intensive culture, a new and promising method for growing wood for energy.

As we have heard, wood is our No. 1 renewable biomasss source for energy and we must have the feedstock before we can convert it to energy. Presently, about 2 quads are generated from wood each year in the United States. This is about 2½ percent of our national energy consumption.

Ten percent of our national energy demands could be satisfied by using wood and wood-derived chemicals in the near future. No other sources of biomass can satisfy such demand without causing major impacts on other resources.

Wood, however, does have it drawbacks. It is bulky, sometimes expensive to collect and often difficult to transport. It is unevenly distributed throughout the country and it has a number of other uses besides energy.

Ideally, a renewable energy resource would occur in large quantities close to a point of use and a continuous supply assured for a long time. Examination of this idea led to the development of the concept of short rotation intensive culture of woody plants. The successful applications of this new and innovative concept would compliment existing wood resources by creating a new supply of wood feedstocks and importantly, insure a stable supply where they are needed.

This additional wood supply potentially equivalent to at least 2 additional quads, according to my estimate, can provide the assurance and long-term supplies that capital investments in wood energy systems require.

Short rotation intensive culture relies on dense spacings of fast growing hardwood species using fertilizers, herbicides, and other techniques to maximize the growth rate of trees and shrubs.

The stands of trees are harvested every 3 to 10 years to capitalize on fast early growth and realize early dollar returns on investment. Expensive replanting is avoided in the short rotation intensive culture concept by encouraging tree stumps to resprout vigorously. Hardwoods which sprout well as a crop have succeeded very well compared to softwoods in the research programs in the United States.

Information about planting techniques, early growth rates and stump sprouting are notably absent.

The short rotation woody crops program was the first and it is the only national program studying short rotation intensive culture in the United States.

With help from the USDA Forest Service and experienced people from industry and universities, the Department of Energy's short rotation woody crops program has identified five major areas of research that are needed to support development of short rotation intensive culture.

One, genetic selection and improvement of woody species. Two, determination of the best management strategies for highest productivity. Three, identification of risk from pests and diseases to minimize productivity losses. Four, the economic evaluations to determine and improve the conditions for the economic viability of this concept. Five, the design of harvesting equipment for small-sized woody material.

Five years, $17 million in Federal funds and about another $4 million in cost sharing from universities and industry have been invested in the establishment and study of field research plots. The study areas total well above a 1,000 acres. Projects are concentrated in the South and the lake States, but include numerous projects in the Northeast, Pacific Northwest, and the Southwest.

Results from these studies are summarized in a document I am submitting for the record entitled, The Short Rotation in Woody

Crops Program, a summary of research sponsored by the Biomass Energy Techology Division.

Results across the country show that average productivity of short rotation standards can be doubled just by selecting and using the appropriate varieties and species. Nationally, 25 species have been indentified as good candidates for short rotation intensive culture and some of them are now undergoing further selection for strains showing higher productivity and hardiness.

Use of fertilizer and weed control appear mandatory for incentive culture crops and can double productivity also. This increased production is in addition to the genetic gains I just mentioned.

Results from experiments indicate that 8- to 10-year crop cycles give the highest average and productivity rates. However, preliminary economic evaluations had, and I emphasize preliminary, indicate the shorter cycles may give better financial results by shortening the period before returns are realized. The trouble is that we don't know what kind of productivity to expect after the first growing cycle. Most of our crops are only 4 years old. Several more years of monitoring and measuring are needed to collect the data to determine the feasibility of the short rotation concept.

The economic feasibility of short rotation intensive culture remains unclear due to signficiant assumptions in the economic evaluations. The most significant assumptions are, one, the cost of harvesting. It is 25 to 60 percent of the total costs and we don't even have the right kind of equipment to harvest these small tress.

Second, productivity levels after the first harvest. We just don't know what they are. And, three, reasons associated with crop failure are essentially unknown.

Importantly, from these studies, sensitivity analysis and economic studies, we have shown that anything affecting productivity is an extremely important variable in economic evaluations.

If commercial operations achieve the same levels of productivity as experimental field plots, they should be feasible now in a number of places. At Kansas State University a preliminary study found that short rotation as a source of energy would be cheaper than fuel oil and competitive with natural gas. This is costing about $2.20 a million BTU in 1980.

Practically, all the projects in the short rotation crops program are collecting productivity data to merge into an economic assessment of short rotation intensive culture in the next few years.

Existing research and short rotation intensive culture is at a critical and very productive stage. Five years have been invested establishing field plots and growing trees to the point of first harvest. Data obtained from stand growth will enable researchers to assess the overall viability of short rotation intensive culture concept, because productivity figures and cost estimates will finally be available on a wide range of sites and for a wide variety of species.

Through the nationally coordinated short rotation woody crops program, we have gained a much better understanding or productivity rates for the first cycle of growth. But research and sprout regrowth after the first harvest will really get to the crux of the short rotation intensive culture concept's viability.

We understand that the Department of Energy's plans for curtailment of the solar energy program will lead to the termination of all research in the short rotation woody crops program. Thus, no funds would be provided in 1983 or subsequent years budgets.

This means that approximately 90 percent of the research on short rotation culture will be stopped and national sharing of results will be terminated.

Much of the Department of Energy's $17 million invested in research plots blocks over the past 5 years will be lost to the premature termination of experiments. Specifically, losses will include one gains in productivity from genetic selection of important species, two, information on productivity and costs after the first growing cycles a key to the concept. Three, the solid comparable economic evaluation of a new and innovative concept across the United States and, four, over 1,000 acres in research plots just now reaching the age of evaluating of critical aspects of short rotation intensive culture.

If support is continued, much of what would be lost without funding could be accomplished over the next few years. To be sure, research on trees and crops by its very nature is long term in some areas such as genetics could not be completed in just a few years.

Short rotation intensive culture has proven to be an important concept and later, the private sector may be willing to assume the responsiblity for development and demonstration.

I have investigated the possiblity over the past couple of months and it appears unlikely that industry will provide substantial support beyound current levels for the next few years. The primary reasons are the state of the economy, which has cost the forest products industry to curtail many of their own research programs and the fact that short rotation intensive culture is still at the very early stages of research. Some of the companies have specifically recommended Federal support for short rotation intensive culture resources.

In summary, I feel short rotation intensive culture is a most appropriate area for Government sponsored research. Short rotation intensive culture systems can play a valuable role in insuring continuous, stable wood supplies where they are needed and would be an ideal supplement to other less stable biomass sources.

Short rotation intensive culture research is long range and innovative and has benefits for many important industries. I believe it is very important to continue the existing research programs on this important source of biomass because progress in this line of research has been rapid and valuable results are within our grasp.

Thank you.

[The prepaid statement of J. W. Ranney follows:]

TESTIMONY PRESENTED TO

SUBCOMMITTEE ON ENERGY DEVELOPMENT AND APPLICATIONS

U.S. HOUSE OF REPRESENTATIVES

May 28, 1982

# Hearings on Renewable Energy in the Eighties: Needs for Further Research, Development and Demonstration

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*Operated by Union Carbide Corporation for the Department of Energy.

INTRODUCTION

My name is J. Warren Ranney. I am a professional forester and ecologist who has been personally involved in research on forest management and productivity since 1970. I am currently a research associate in the Environmental Sciences Division at Oak Ridge National Laboratory at Oak Ridge, Tennessee. I serve as the Field Program Manager for the U.S. Department of Energy's (DOE) Short Rotation Woody Crops Program and in this position I am responsible for the technical guidance of the thirty research projects in the program. This research is located in all regions of the country that appear capable of supporting short-rotation intensive culture. Most of the projects are located at universities; some USDA-Forest Service experiment stations and private industries also participate. Today I am going to talk about short-rotation intensive silviculture, a new and promising method of growing wood for energy.

The information I will present today reflects my judgments and opinions as affected by my constant contact with the university faculty comprising the Short Rotation Woody Crops Program, members of the USDA-Forest Service, the forest products industry, and electrical utilities. I have also served as the United States representative to the International Energy Agency's (IEA) working group on forest growth and production. The member countries participating in this effort have placed considerable importance on short-rotation intensive culture. My staff and I have had the key responsibility for assisting DOE in preparing research plans for the national Short Rotation Woody Crops Program since 1976 and have been solely responsible for the technical management and integration of research to test the viability of the concept of short-rotation intensive culture of woody plants.

## SIGNIFICANCE OF SHORT-ROTATION INTENSIVE CULTURE

Wood is our number one renewable biomass source of energy. Right now, about two quadrillion Btu's (2 quads) are generated from wood each year in the United States. This is about 2.5 percent of our national energy consumption. Ten percent of our national energy demands could be satisfied by using wood and wood-derived chemicals in the near future. No other source of biomass can satisfy such a demand without incurring major impacts on other resources. Wood, however, does have its drawbacks. It is bulky and difficult to transport. It is widely, yet unevenly, distributed throughout the country, and it has a number of uses besides energy.

Ideally, an energy resource would occur in large quantities close to a point of use with a continuous supply assured over a long period of time. Examination of this ideal led to the development of the concept of short-rotation intensive culture of woody plants. The successful application of this new and innovative concept could complement existing wood resources by creating a new supply of wood feedstocks to ensure stable supplies where they are needed. This additional wood supply, potentially equivalent to at least two additional quads according to my estimate, is important in the realistic development of wood energy resources because it can provide the assurance of long-term supplies that capital investments in wood energy systems require.

## DEFINITION OF SHORT-ROTATION INTENSIVE CULTURE

Short-rotation intensive culture relies on dense spacings of fast growing hardwood species on well-prepared land, using fertilizers, herbicides, and other agronomic techniques to maximize the economical growth rate of the trees and shrubs. The closely spaced rows of trees are harvested every three to ten years to capitalize on fast early growth and to realize early dollar returns on investments. This is different from conventional forestry which commonly carries investments 25 to 30 years before realizing any returns. Expensive replanting is avoided in the short-rotation intensive culture concept by encouraging stumps to resprout vigorously . This last point -- reestablishing wood crops by stump sprouts (coppicing) -- is a key aspect of short-rotation intensive culture. Besides saving time, money and energy, it places restrictions on the types of woody plants that can be used. Plants that can sprout well from stumps are generally hardwoods (deciduous trees) and shrubs. This group of woody plants has received very little study compared to softwoods (conifers) in forestry research programs in the United States, and information about planting techniques, early growth rates, and stump sprouting is notably absent.

## MAJOR AREAS OF RESEARCH

Research in short-rotation silviculture has been going on since the late 1960s. Early studies were small, scattered, and directed toward producing biomass for non-energy uses. However, results were promising enough to start a research program in earnest in 1978, when the importance of biomass as a renewable energy resource was recognized. The

Department of Energy's Short Rotation Woody Crops Program was the first and is the only national program studying short-rotation intensive culture in the United States. With help from the USDA-Forest Service and experienced people from industry and universities, the Department of Energy's Short Rotation Woody Crops Program has identified the following major areas where research is needed to support the development of short-rotation intensive culture.

* Genetic selection and improvement of woody species.
* Determination of the optimum relationships between plant spacing and timing of harvests for maximum productivity.
* Determination of the effects of fertilizer, weed control, irrigation, and other strategies on productivity.
* Identification of risks from pests and diseases to minimize losses.
* Economic evaluations, including sensitivity analyses, to determine the conditions for economic viability and to guide research.
* Design of harvesting equipment for small-sized woody material.

## RESEARCH RESULTS

Five years, $17 million in federal funds, and about another $4 million in cost-sharing from universities and industry have been invested in the establishment and study of field research plots. The study areas total well over a thousand acres and are in all regions of the country which appear capable of supporting short-rotation intensive culture. Results of these studies are summarized in a document I am submitting for the record entitled "The Short Rotation Woody Crops Program: A Summary of Research Sponsored by the Biomass Energy Technology Division."

Potential improvements in productivity through careful selection of hardy fast-growing trees now appear greater than first believed. The University of Washington has developed a hybrid cottonwood which produced about ten dry tons per acre per year over a three-year period, more than double normal productivity. Industry is already interested in this hybrid and is eager for research to continue. Even higher productivity rates are being achieved in Florida and Hawaii with species of eucalyptus. The University of Vermont, which has plots throughout Vermont and in northern New York, has identified some native trees having the highest potential for energy production under short-rotation intensive culture in the Northeast, including silver maple, black locust, and hybrid poplar. Work with native and exotic shrubs in the semi-arid areas of Arizona, California, Texas, and Utah has produced selected species and strains which show productivity at least three times as high as unselected material. Semi-arid developing countries have been extremely interested in our results. In general, results across the country show that the average productivity of short-rotation stands can be doubled just by selecting and using appropriate varieties and species. Nationally, twenty-five species have been identified as good candidates for short-rotation intensive culture, and some of them are now undergoing further genetic selection for strains showing higher productivity and hardiness.

Fertilizers and weed control appear mandatory for ensuring the success of short-rotation intensive culture crops. Experiments at Pennsylvania State University demonstrated that productivity can be doubled using the proper combination of the two, more than recovering their costs. In contrast, increases in productivity from irrigation did not justify the investment required for the irrigation system. Similar results have been seen in Georgia, Illinois, Wisconsin, Michigan, and Washington. In Florida, expensive nitrogen fertilizer was not needed at all. Fertilization with phosphorus alone produced biomass in excess of ten dry tons per acre per year, while without fertilization, almost nothing grew. We have found that fertilizers and weed control are needed in most situations to ensure good crops and now we are determining the most economical levels to apply.

It is more difficult to establish stands of hardwood (deciduous) trees and shrubs than pines, and a large amount of research has been directed toward developing techniques for ensuring successful establishment and rapid early growth in short-rotation intensive culture plantations. Much progress has been made, and researchers can now expect 90 to 95 percent plantlet survival, with rapid early growth, under a wide variety of experimental conditions. However, the techniques have not been tested under conditions that simulate commercial situations except in Michigan, Georgia, and Hawaii, and experience at these places indicates some additional experimentation will be needed to adapt techniques developed on research plots to large-scale field plantings.

Results from most of the experiments in the Short Rotation Woody Crops Program indicate that eight- to ten-year growth periods give the highest average annual productivity rates. However, preliminary economic evaluations indicate that shorter cycles may give better financial results by shortening the period before returns are realized. All existing economic studies are dominated by major assumptions about long-term short-rotation intensive culture productivity rates, because most of our data comes from research plots that are now four years old. Plantings in most studies started under the Short Rotation Woody Crops Program have only recently been harvested for the first time, and critical questions remain about productivity rates in later growing cycles. Preliminary studies indicate that productivity during regrowth will be about 30 percent higher than in the first growing period because the stumps already have vigorous root systems. However, the success of second growth in many species remains largely unknown, and except for sycamore and poplar, almost nothing is known about the survival and growth of woody species through repeated cycles of cutting and regrowth. The research which will give us this information is well underway, but several more years of monitoring and measuring are needed to collect the data that will allow us to determine the feasibility of the short-rotation concept.

The risks of losing crops to pests, diseases, and unusual weather are also very poorly understood for short-rotation intensive culture. Experience indicates that these risks will be substantial, though economic evaluations have thus far failed to account for them because there has been no information published to indicate their possible magnitude. Because an understanding of risks is necessary for evaluating the viability and possible use of short-rotation intensive culture, efforts are being made to understand the effects of pests and weather, but much remains to be accomplished.

Harvesting of short-rotation materials offers problems for equipment design. At harvest, trees and shrubs will be too large for existing agricultural machinery, but too small for conventional tree harvesters which cut one tree at a time and must harvest trees above five inches in diameter to operate efficiently. In addition, in short-rotation intensive culture the stumps must remain in relatively good condition to enable adequate resprouting for the next crop. Conceptual designs for short-rotation intensive culture harvesters have been developed and are being tested at Virginia Polytechnic Institute and State University in concert with the USDA-Forest Service, the pulp and paper industry, and the International Energy Agency. Actual equipment prototype construction is not planned as part of the Short Rotation Woody Crops Program, although field testing will eventually be necessary. Appropriate equipment development is required before the short-rotation intensive culture concept can be evaluated on the basis of economics.

It is now clear that the economic feasibility of short-rotation intensive culture depends on factors that are either very site specific, largely undefined, or both. The most significant of the undefined factors are (1) the cost of harvesting, which is the largest single cost factor (25 to 60 percent of total costs), (2) productivity levels after the first harvest, and (3) the risks associated with crop failure. Harvesting costs are important because they appear to be such a large portion of total production costs, yet there is no equipment designed to harvest short-rotation intensive culture crops. Productivity levels after first harvest are important for what are expected to be long-lived stands of trees (root stocks are expected to survive at least three to five harvest cycles). Sensitivity analyses have shown that anything which affects productivity is an extremely important variable in economic evaluations. Land costs and product prices are also important variables but variables over which researchers have little control.

If commercial operations could achieve the same levels of productivity as experimental field plots, they should be feasible now in a number of places. At Kansas State University a preliminary economic study found that short-rotation wood as a source of energy would be cheaper than fuel oil and competitive with natural gas costing about $2.20/million Btu's. Another study in Illinois showed that short-rotation intensive culture wood would be competitive only with fuel oil. Oak Ridge National Laboratory is developing a system for evaluating different short-rotation intensive culture approaches around the country on a common, comparable basis. In addition, practically all projects in the Short Rotation Woody Crops Program are collecting cost and productivity data to merge into an economic assessment of short-rotation intensive culture in the next few years. This research has initiated the first intensive evaluations of short-rotation intensive culture on a wide variety of sites. At this point we have information only on costs and productivity from the initial growing cycle. Other information must be assumed until, over the next few years, the actual costs and productivities are determined.

## CONCLUSIONS AND RECOMMENDATIONS

Existing research on short-rotation intensive culture is at a critical and very productive stage. Five years have been invested in establishing field plots and growing trees to the point of first harvest. Data obtained from stand regrowth will enable researchers to assess the overall viability of the short-rotation intensive culture concept, because productivity figures and cost estimates will finally be available for a wide range of species and sites. Through the nationally coordinated Short Rotation Woody Crops Program, we have already gained a much better understanding of cultural requirements and productivity rates for the first cycle of growth, but research on sprout regrowth after first harvest (coppice) will really get to the crux of the short-rotation intensive culture concept's viability.

We understand that DOE's plans for curtailment of the Solar Energy Program would lead to termination of all research in the Short Rotation Woody Crops Program. Thus, no funds would be provided in the FY-1983 or subsequent years budgets. This means that approximately 90 percent of the research on short-rotation intensive culture will be stopped and national sharing of results will be terminated. Much of DOE's $17 million invested in research plots over the past five years will be lost due to the premature termination of experiments. Specifically, losses will include:

- Many of the gains that were planned from genetic selection of species since considerable screening has been completed in preparation for this.
- Information on management approaches, productivity, and costs of short-rotation intensive culture after the first growing cycle -- the key to the concept.
- A solid economic evaluation of a new and important concept under a wide variety of conditions with accurate information.
- Over a thousand acres in research plots which have been maintained and studied for five years to reach the point of evaluating the critical aspects of short-rotation intensive culture.

If support is continued, much of what would be lost without funding could be accomplished over the next few years. To be sure, some areas of research such as genetics are long-term and could not be completed in just a few years. But an additional point may be worth consideration. Short-rotation intensive culture is proving to be an important concept, and later the private sector may be willing to assume the responsibility for development and demonstration. Presently, representatives of the forest products industry and energy-related companies (utilities and chemical companies) feel that short-rotation woody crops are a potential long-term source of energy and chemical feedstocks, but that more research is needed before it can be considered for adoption on a commercial scale. I have evaluated the possibility of industrial support for short-rotation intensive culture research. In general, it is unlikely industry will provide any substantial direct support beyond current levels (roughly 25 to 30 percent cost-sharing in the federal research program) for the next few years. The primary reasons are the state of the economy, which has caused the forest products industries to curtail many of their own research programs, and the fact that short-rotation intensive culture research is still in the very early stages. Some companies, such as Crown Zellerbach and Buckeye Cellulose, have specifically recommended continued federal support for short-rotation intensive culture research.

In summary, I feel that short-rotation intensive culture is a most appropriate area for government-sponsored research. Standing forest inventories may contribute more total biomass to our immediate energy supplies, and little research is needed to use them. But short-rotation intensive culture systems, adjusted for local conditions, can play the very valuable role of ensuring continuous, stable wood supplies where they are needed, and will be an ideal supplement to other less stable biomass sources. Short-rotation intensive culture research is long-range and innovative, and has benefits for many important industries. In the Short Rotation Woody Crops Program, we have seen how having a coordinated national research program covering a wide range of species and sites provides a means for the interchange of ideas and results among investigators and promotes the fastest overall development and assessment of the short-rotation intensive culture concept. I believe it is very important to continue the existing research programs on this important source of biomass because progress in this line of research has been rapid and valuable results are within our grasp.

# THE SHORT ROTATION WOODY CROPS PROGRAM: A SUMMARY OF RESEARCH SPONSORED BY THE BIOMASS ENERGY TECHNOLOGY DIVISION

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April 1982

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## 1.0 INTRODUCTION

This report provides a summary of the Short Rotation Woody Crops Program (SRWCP) sponsored by the Biomass Energy Technology Division of the U.S. Department of Energy (DOE) with field management by the Environmental Sciences Division of Oak Ridge National Laboratory (ORNL). The report, designed to serve as an introduction to the SRWCP, presents the program's objectives, approach, and research activities.

The SRWCP is an integrated program of research on a single concept, the short-rotation intensive culture (SRIC) of hardwood trees and shrubs.

SRIC relies on using selected, fast growing species, fertilizers, weed control, and other agronomic techniques applied to trees and shrubs to maximize their rate of biomass production. The SRIC concept also includes harvests as often as every 3 to 10 years followed by regrowth from the existing stumps.

Conceptually SRIC appears promising, especially in the face of a decreasing land base and increasing demands for all types of biomass products. But major questions remain about the biological productivity rates, costs, risks, and profits of short-rotation systems.

Seeking to answer some of these questions, and to improve the productivity and increase the cost efficiency of growing woody plants for fuel and petrochemical substitutes, DOE issued a Program Research and Development Announcement (PRDA) on fuels from woody biomass in late 1977. The PRDA asked for research proposals in three major areas: (1) the selection of species with promise for SRIC; (2) stand establishment and management strategies for SRIC; and (3) harvest, collection, transportation, and storage strategies for SRIC. In a competitive technical review, 25 of the proposed projects were chosen to form a new research program. The SRWCP, then called the Fuels and Chemicals from Woody Biomass Program, began with those projects. While some of the original projects have ended and new ones have begun, the long-term research projects dating to the original PRDA still form the core of the SRWCP.

The SRWCP is a national program of basic research on SRIC. It relies heavily on field studies located in the regions which appear to have significant areas of land suitable for SRIC. Because climatic and site conditions vary greatly across the United States, regional approaches to SRIC also vary, and a large number of sites and systems must be examined before the results can be generalized with any confidence. The program is designed so information will flow among all research areas and projects. The linkages among them are absolutely necessary for testing and improving the SRIC concept as quickly as possible.

Coordinating research on SRIC in a single program permits efficient use of the research funds required to produce the information needed to assess SRIC on a national basis. The research itself benefits, because SRIC systems and SRIC research across the country have elements in common, and investigators from all the research projects meet regularly to exchange information about their latest problems and progress. The ultimate assessment of SRIC as a biomass-producing technology also benefits, because the research projects have been designed to provide consistent results at nearly the same time. Any research on tree growth, even research systems designed for quick returns, takes time. Synchronizing SRIC research across the country will minimize the amount of time that must pass before the costs and benefits of SRIC can be evaluated.

Oak Ridge National Laboratory is conducting in-house research in support of program-wide coordination and concerns in the SRWCP. The support involves development and application of economic evaluations of subcontracted field research. This work has been jointly undertaken by the Energy Division and the Environmental Sciences Division to prepare comparable economic evaluations and sensitivity analyses between SRWC projects while recognizing the need for cooperation between biological and economic disciplines in developing evaluations and guiding research. The Environmental Sciences Division is also conducting field research on nutrient movement in woody biomass production systems. The objectives are to better understand both management of biomass production systems (efficient nutrient use) and some major environmental implications of intensifying woody biomass management and removal. Research results from these areas are coordinated with the Department of Energy's Biomass Energy Technology Division through the Division's Program Manager for Environmental Studies.

This report is divided into six major parts. The first discusses the general objective of the SRWCP, and the second describes the approach being taken in the SRWCP to reach that objective. The following three sections cover the three major reseach areas in the SRWCP, discussing their status, their specific research goals, and some recent research results. The final section contains brief summaries of the individual research projects in the program.

## 2.0 PROGRAM OBJECTIVES

The overall objective of the SRWCP is to attain high productivity rates at competitive prices. This requires that research define the potential productivity of woody species under intensive culture and to develop the capability for producing woody biomass with SRIC by improving the productivity and increasing the cost-efficiency of SRIC systems. Specific goals, listed below, have been established for each of the major research areas in the SRWCP.

1. The objective of the species selection research is to improve the productivity of SRIC by testing, selecting, and developing species and strains of trees and shrubs for use in intensively managed systems.

2. The objective of the stand management research is to improve the productivity and decrease the costs of SRIC by developing effective and efficient techniques for SRIC stand establishment and management.

3. The objective of the economic studies is to increase the cost efficiency of SRIC by integrating economic considerations into SRIC system design and research planning.

Achievement of these objectives will be measured by:

1. Defining SRIC systems suitable for a range of available sites across the country, and establishing their baseline costs and biological productivities, and

2. Developing SRIC systems whose technical and economic readiness for producing woody biomass can be demonstrated.

## 3.0 APPROACH

Resource management is the key to maintaining a supply of wood for energy. In the face of declining forest acreages and projected increases in demands for all types of wood products, short-rotation intensive culture (SRIC) may become an important management approach. SRIC has as its objective producing the maximum sustainable amount of wood per unit of land each year. SRIC systems adjusted to local conditions would permit wood to be grown where needed, using available sites. It would require the least amount of land of all forest management approaches.

Realizing the potential of wood as an energy feedstock, the U.S. Department of Energy started the Short-Rotation Woody Crops Program (SRWCP) in 1978 to examine the possibilities for SRIC across the country and to improve the biological productivity and economic efficiency of SRIC systems. Prior to the SRWCP, experience with SRIC was limited to a few species on a few types of sites. The SRWCP was designed to provide baseline information about a much larger range of species and sites and to improve the productivity and efficiency of those systems. Most of the research projects are at universities, though some of the research is being done by private corporations and some by the U.S.D.A. Forest Service. Figure 3.1 shows the locations of the active SRWCP research projects. The SRWCP is now providing a comprehensive, consistent data base on SRIC. It is already possible to draw some conclusions about early SRIC productivity from SRWCP research. Most of the field studies supported by the SRWCP are now four years old, and their experimental plantings are reaching the projected age of first harvest. The SRWCP data base will be even more valuable as these research plots are harvested and their regrowth is recorded and compared.

There are three major research areas in the SRWCP: (1) species selection, (2) stand management, and (3) economic studies. Figure 3.2 shows the structure of the program and the individual research projects in each area. The specific objectives of each research area are discussed in later sections. Four major products will be produced by the program as a whole by 1987. These products, which will integrate information from all three research areas, are:

1. A definition of the conditions under which SRIC is economically viable;
2. Descriptions of the most promising SRIC systems for each region, and comparisons among regional outlooks for SRIC;

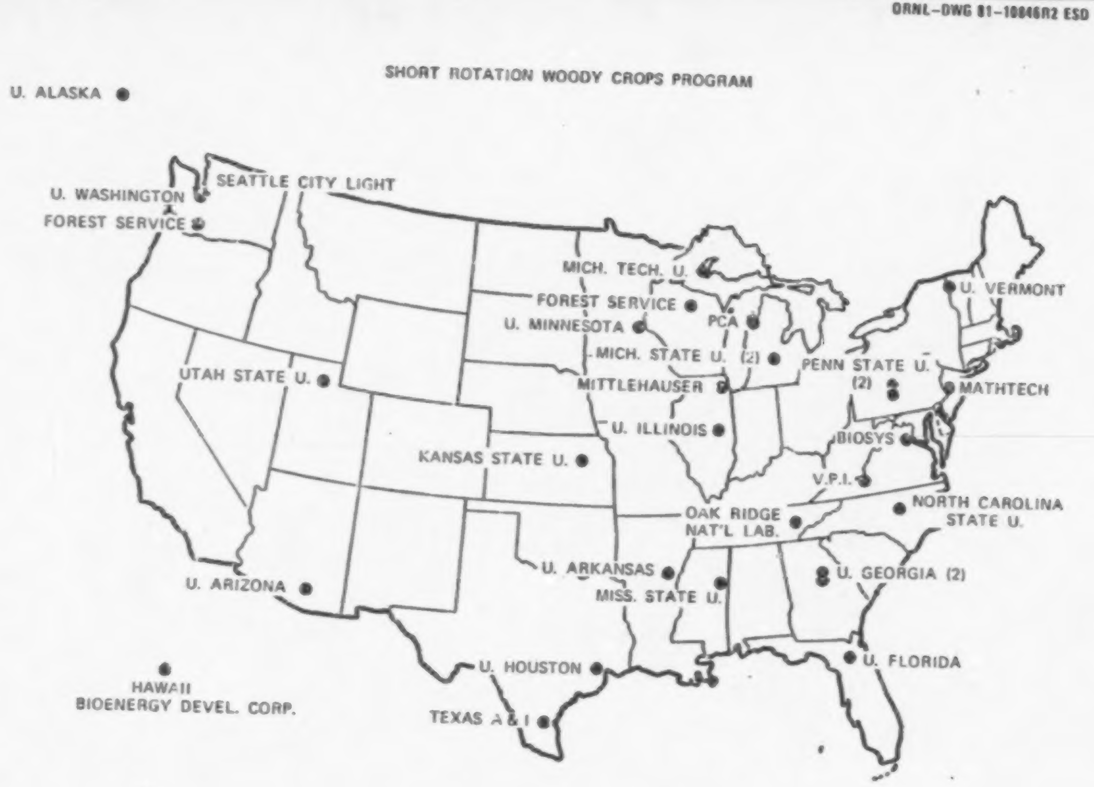

Figure 3.1 RESEARCH IN THE SHORT ROTATION WOODY CROPS PROGRAM IS LOCATED IN ALL THE MAJOR WOOD-PRODUCING REGIONS OF THE UNITED STATES

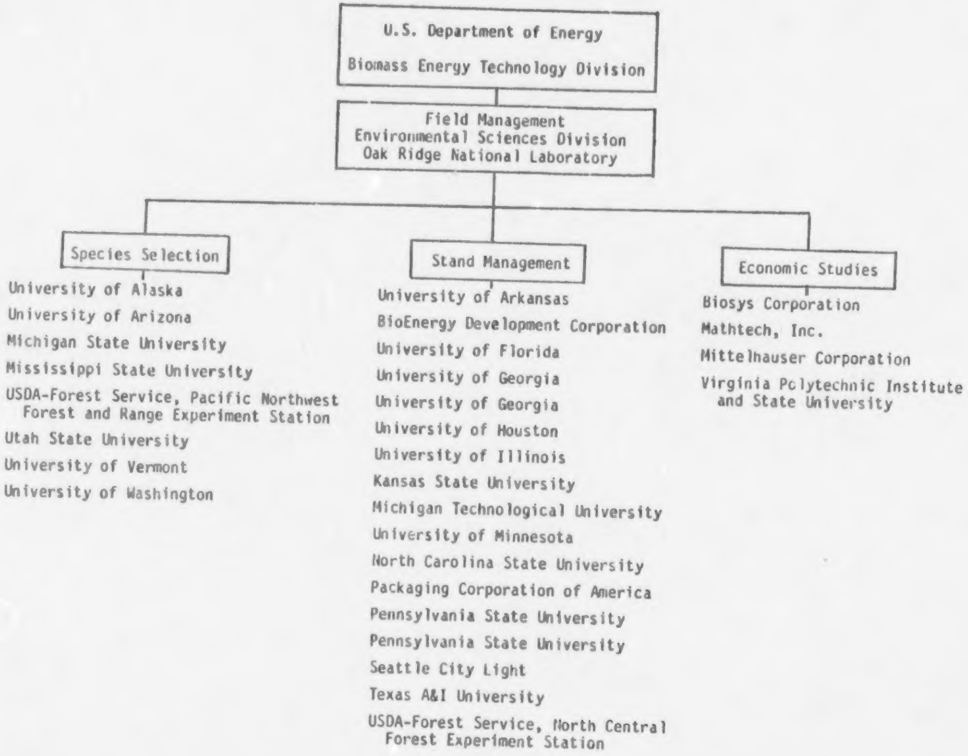
U.S. Department of Energy
Biomass Energy Technology Division
Field Management
Environmental Sciences Division
Oak Ridge National Laboratory
Species Selection
University of Alaska
University of Arizona
Michigan State University
Mississippi State University
USDA-Forest Service, Pacific Northwest Forest and Range Experiment Station
Utah State University
University of Vermont
University of Washington
Stand Management
University of Arkansas
BioEnergy Development Corporation
University of Florida
University of Georgia
University of Georgia
University of Houston
University of Illinois
Kansas State University
Michigan Technological University
University of Minnesota
North Carolina State University
Packaging Corporation of America
Pennsylvania State University
Pennsylvania State University
Seattle City Light
Texas A&I University
USDA-Forest Service, North Central Forest Experiment Station
Economic Studies
Biosys Corporation
Mathtech, Inc.
Mittelhauser Corporation
Virginia Polytechnic Institute and State University

FIGURE 3.2 RESEARCH PROJECTS IN THE SHORT ROTATION WOODY CROPS PROGRAM ARE DIVIDED INTO THREE MAJOR SUBJECT AREAS

3. A national estimate of the biomass production potential of SRIC, and

4. A discussion of the major assumptions used to produce item (3), and the information still needed to verify them.

Considerable field experimentation and economic evaluation are still required to create these products. However, intermediate products, including a bank of information on species-site relationships, are already being produced. Cost and risk analyses for SRIC systems will be a continuing part of program management and research planning.

The research on stand management is complex enough to warrant further description here. Figure 3.3 diagrams the subjects covered in this area, which contains the majority of research in the SRWCP and is also the critical time path in attaining the program's objective. Stand management research is studying the relationships among site types, species, management approaches, and productivity rates. The economic viability of SRIC systems will depend on the productivity rates attained and the costs of the management systems used to reach them. Until these relationships are defined for a range of regions, sites, and species, predictions about SRIC will remain speculative and uncertain. Figure 3.4 shows the flow of information among tasks through the projected lifespan of the SRWCP, and emphasizes the central position of the biological results from the stand management studies in the overall program.

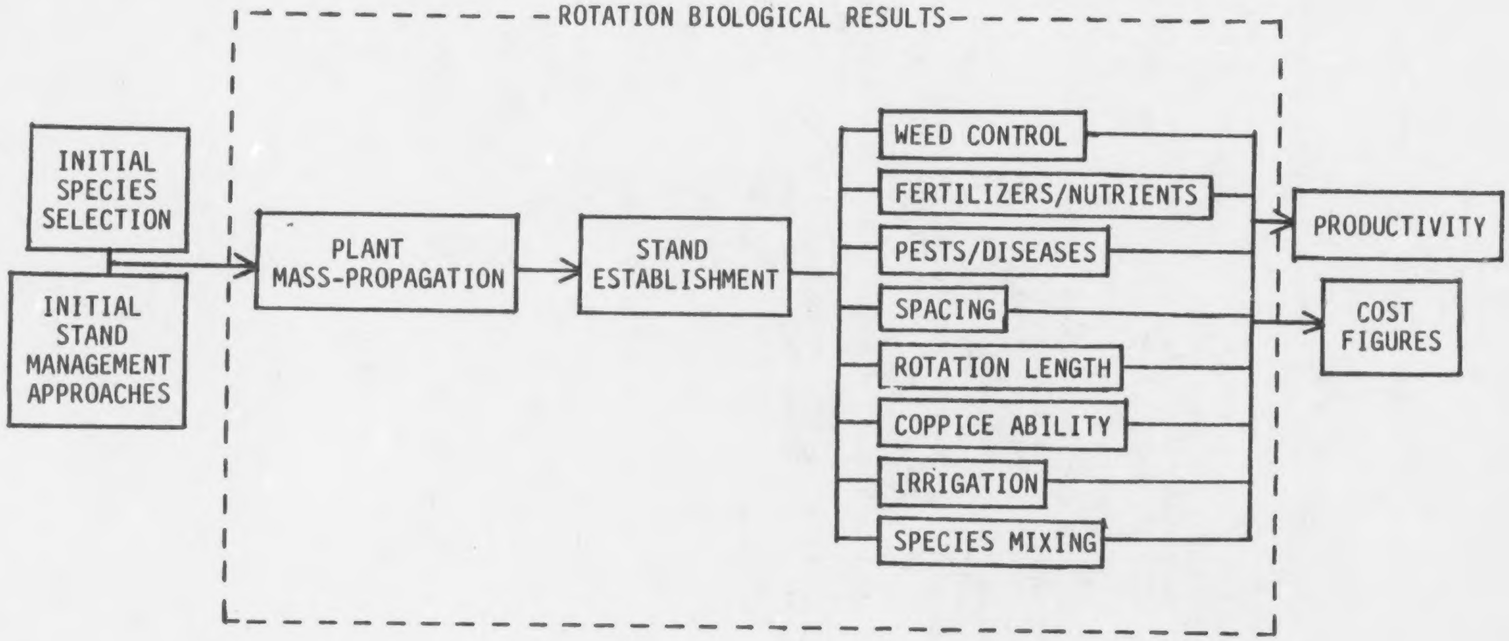

FIGURE 3.3 SUBTASKS IN THE STAND MANAGEMENT AREA COMPRISE THE PREDOMINANT ACTIVITY WITHIN THE SHORT ROTATION WOODY CROPS PROGRAM

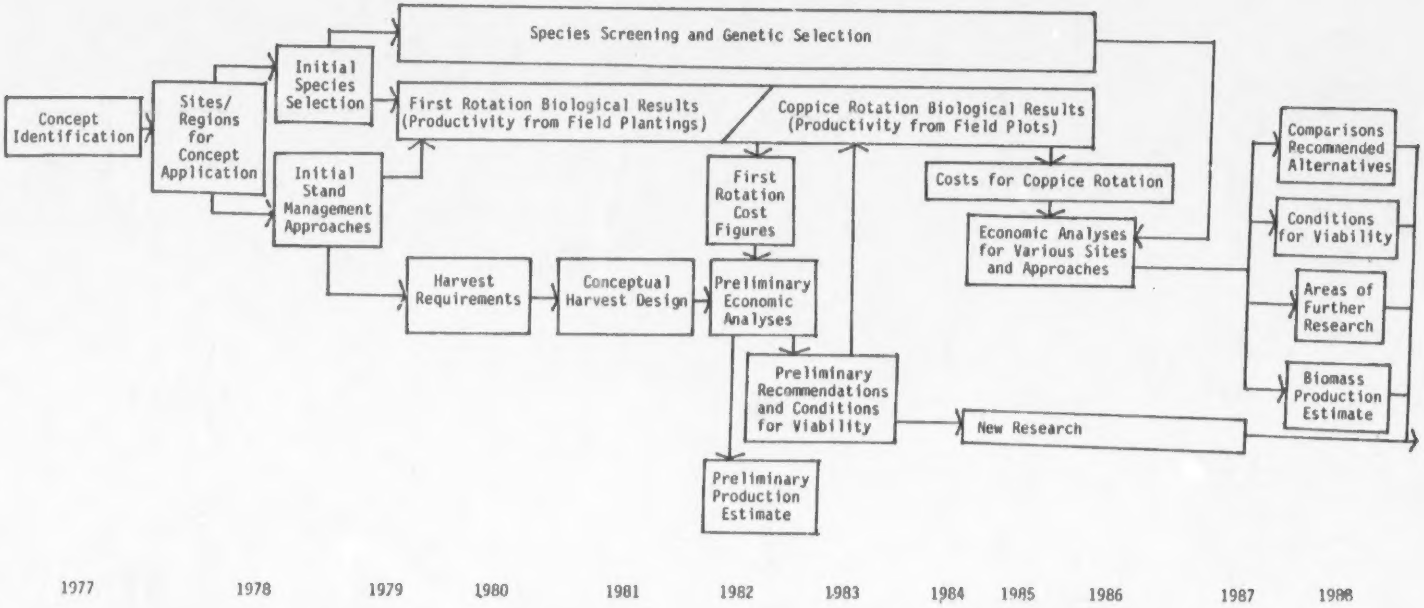
Concept Identification
Sites/ Regions for Concept Application
Initial Species Selection
Initial Stand Management Approaches
Species Screening and Genetic Selection
First Rotation Biological Results (Productivity from Field Plantings)
Coppice Rotation Biological Results (Productivity from Field Plots)
Harvest Requirements
Conceptual Harvest Design
First Rotation Cost Figures
Preliminary Economic Analyses
Preliminary Recommendations and Conditions for Viability
Preliminary Production Estimate
Costs for Coppice Rotation
Economic Analyses for Various Sites and Approaches
New Research
Comparisons Recommended Alternatives
Conditions for Viability
Areas of Further Research
Biomass Production Estimate
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988

FIGURE 3.4 INFORMATION WILL FLOW AMONG TASKS IN THE SHORT ROTATION WOODY CROPS PROGRAM. THE PROJECTED TIME FRAMES FOR RESULTS FROM SPECIFIC PROJECTS AND REGIONS WILL OVERLAP.

# 4.0 SPECIES SELECTION STUDIES

## 4.1 APPROACH

The species screening and genetic selection studies are designed to improve the productivity of SRIC by identifying superior species, strains, and hybrids of trees and shrubs for intensively managed systems. Selection work is proceeding at several levels. Many species which appear to have desirable characteristics have never been grown under intensive culture before, and are now being tested for the first time. Some species which appeared promising in early SRIC trials are being examined in more detail in studies designed to determine the amount of genetic diversity available for selection. Experimental hybridization is also being used to produce strains with traits especially valuable in SRIC.

The goals of the four major stages of selection studies are:

1. Identify the best woody species for SRIC systems in each major region of the United States which appears to have potential for supporting SRIC.

2. Define the genetic diversity within promising species to identify the possibilities for further improvement.

3. Select strains within species or hybridize species for traits valuable in short-rotation systems.

4. Test the selected species, strains, and hybrids for production under intensive management on a range of sites.

## 4.2 RESULTS AND IMPLICATIONS

The results from first-generation genetic selection studies in the SRWCP give an indication of improvements in productivity which may be possible using selected stock. Table 4.1 summarizes these tests, in which the best individuals grew almost 50% more than average. Later generations of selection studies could easily raise this figure. Of special significance are the results from Mississippi on sycamore. They indicate selection for disease resistance could improve productivity by 17%, and selection for dry matter production could add an additional 10 to 25% to yield a total increase of 27 to 42% above current average yields. Selection may offer such improvements for other species too, although the range of possible improvements is not known for the vast majority of hardwood species and sites. Genetic studies related to tree improvement hold great promise and have a high research priority. They may become even more important if conversion processes sensitive to wood components are developed, and genetic studies become the link between biomass production and its end uses.

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## TABLE 4.1 ANTICIPATED AND REALIZED PRODUCTION GAINS THROUGH GENETIC SELECTION

| SPECIES | LOCATION | PERCENT PRODUCTION GAIN | VARIABLE |
|---|---|---|---|
| SYCAMORE | MISSISSIPPI | 17 | DISEASE RESISTANCE |
| SYCAMORE | MISSISSIPPI | 10 | DRY MATTER PRODUCTIVITY |
| SYCAMORE | MISSISSIPPI | 25 | DRY MATTER PRODUCTIVITY |
| SLASH PINE | FLORIDA | 90 | EXTRACTIVE PRODUCTIVITY |
| EUCALYPTUS | FLORIDA | 50 | VOLUME |
| SAND PINE | FLORIDA | 83 | ENERGY CONTENT |
| BLACK COTTONWOOD | WASHINGTON | 47 | DRY MATTER PRODUCTIVITY |
| BLACK COTTONWOOD | WASHINGTON | 50 | DRY MATTER PRODUCTIVITY |
| MESQUITE | CALIFORNIA | 50 | DRY MATTER PRODUCTIVITY |
| EUCALYPTUS | HAWAII | 15 | VOLUME |
| HYBRID POPLAR | VERMONT | 100 | DRY MATTER PRODUCTIVITY |

# 5.0 STAND MANAGEMENT STUDIES

## 5.1 APPROACH

Stand management studies are improving the productivities and decreasing the costs of SRIC by developing efficient techniques for establishing and maintaining SRIC systems. This area contains the largest number of individual research projects in the SRWCP and covers the largest number of research topics.

Stand management research is being performed in different regions and on different sites. Therefore, even projects covering the same subjects are not duplicating work but are producing complementary information which will be very important in assessing and improving the economic efficiencies of SRIC. The data linking specific management practices and their costs to productivity rates will later be used in economic studies to evaluate SRIC systems and their components.

The specific goals of the SRWCP stand management research, listed below, will all lead to information needed to evaluate SRIC as a biological and economic concept.

1. Develop procedures which permit a high degree of genetic control for the mass propagation of planting material.
2. Develop and improve techniques for assuring high survival and rapid early growth of newly planted seedlings and cuttings.
3. Identify the most efficient means for controlling competing vegetation in SRIC.
4. Determine the most cost-effective systems for using fertilizers in SRIC.
5. Determine the costs and benefits of using irrigation in SRIC.
6. Determine the relationships among species, spacing, rotation length, and production in SRIC.
7. Determine the major pests and diseases in SRIC systems, and develop ways to control them.

## 5.2 RESULTS AND IMPLICATIONS

The productivity rates seen to date in over 350 different tests of SRIC are presented in Figure 5.1. These rates are the results of the first SRIC studies in the United States, and in many cases do not include rates of coppice regrowth because the stands are not yet old enough. The productivity rates in Figure 5.1, average 6 dry Mg $ha^{-1}$ $year^{-1}$ [2.64 dry tons $acre^{-1}$ $year^{-1}$].

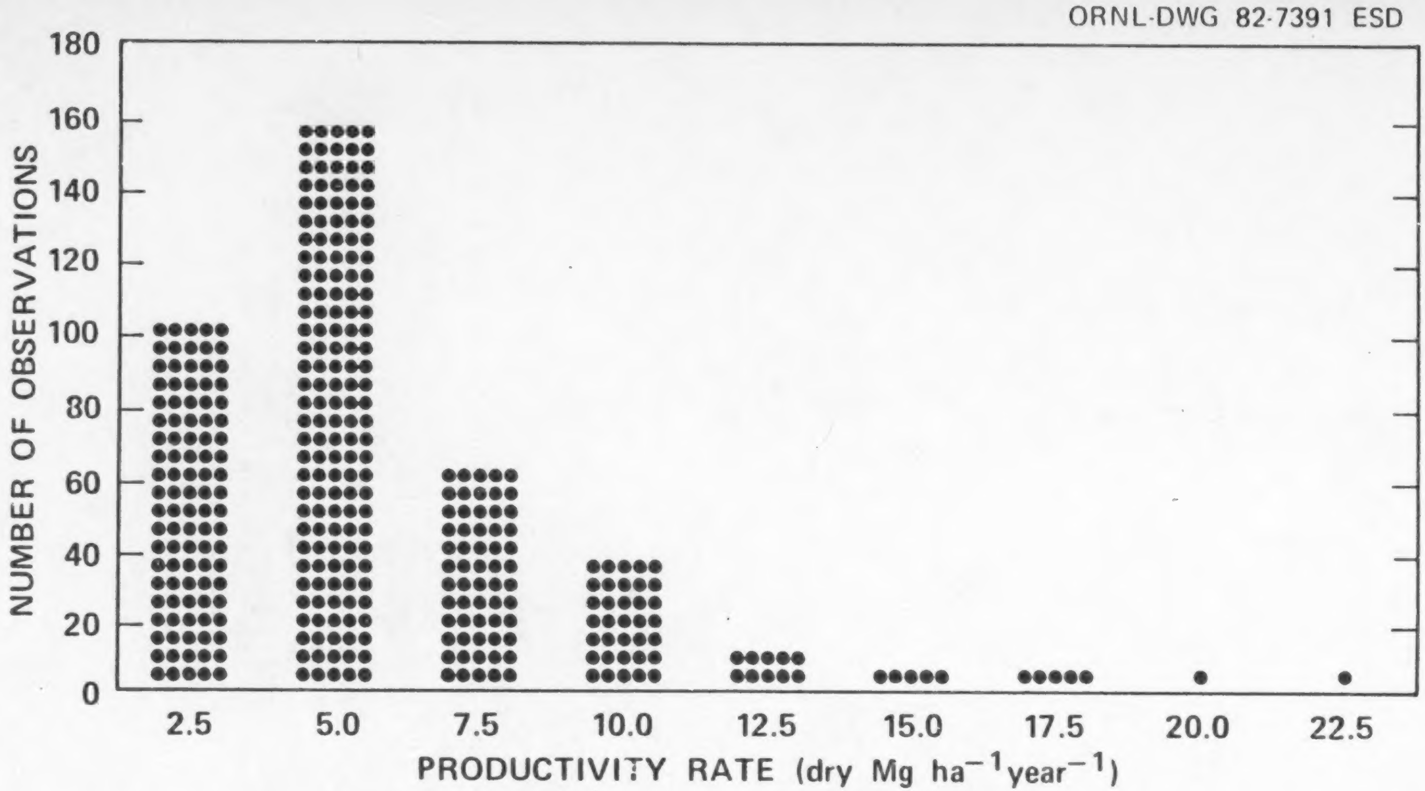

FIGURE 5.1 SRIC PRODUCTIVITY RATES OBSERVED IN THE U.S.A.
(SINGLE SYMBOLS REPRESENT FEWER THAN FIVE OBSERVATIONS)

Though these rates are low compared to some predictions for SRIC, they do not mean the predictions are misleading. By learning from mistakes and taking advantage of successes, the average productivity rates in ongoing studies should now improve rapidly. By concentrating on the best management techniques from the early studies, later figures should be at least 125% higher. The results shown in Figure 5.1 are based on a wide variety of sites, generally unimproved stock, and a wide variety of spacings, ages, fertilizer levels, and weed control regimes. All these factors offer ways to improve productivity or lower costs. Figure 5.2 geographically displays the productivity rates used to make Figure 5.1 show regional differences. Figure 5.3 shows the projected productivity rates that species screening and stand management research indicate should be possible for a wide range of sites and species.

Weed control in SRIC, as in agriculture, has proven critical for maximizing productivity per unit land. During the first few growing seasons chemical or mechanical weed control appears mandatory and can improve productivity by as much as 100% over plots receiving only pre-planting weed control. Lack of any weed control treatment often leads to the total failure of hardwood crops.

Fertilizers are also almost mandatory for achieving high productivity levels. Figure 5.4 shows the effect of fertilizer on productivity rates over a wide range of site types, climates, and management approaches. The figure suggests productivity can be more than doubled over the first four or five years, and results from specific experiments indicate that the increase levels off at rotation ages above 5 to 8 years.

Improvements in productivity can also be made through careful spacing of crops and timing of harvests. For the most efficient use of a site both of these factors must be directly tied to the growth rate of the trees. Experimental results suggest that spacings of two meters or more between trees, and harvests around eight years apart yield the most biomass. Harvests of coppice regrowth (stump sprouts) are expected to yield 30% more biomass per year of growth than the first harvest, but data are so limited that generalizations are probably very inaccurate. Because information on coppice growth is important for evaluating SRIC, coppice regrowth cycles are the focus of much attention in current SRWCP research.

Diseases and pests have been only minor problems in SRIC to date, but they are expected to become more common as hardwood plantations become larger, older, and more widespread. If not controlled, they could cause significant decreases in productivity. The SRWCP research projects are constantly monitoring for pest and disease problems, and integrated pest management research is expected to be a continuing part of program research.

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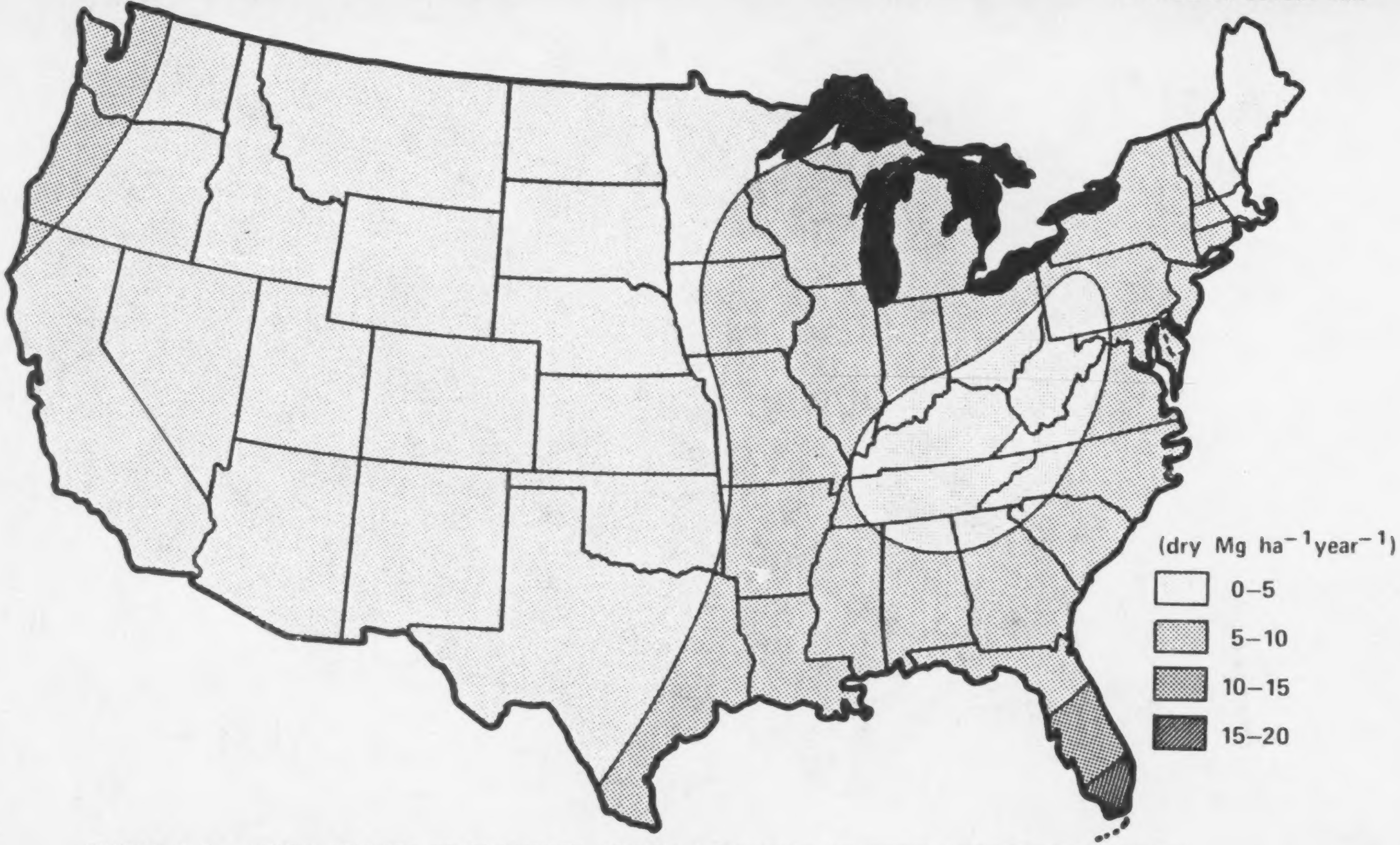

FIGURE 5.2 WOODY BIOMASS PRODUCTIVITY COMMONLY ACHIEVED ON SITES OF MODERATE QUALITY

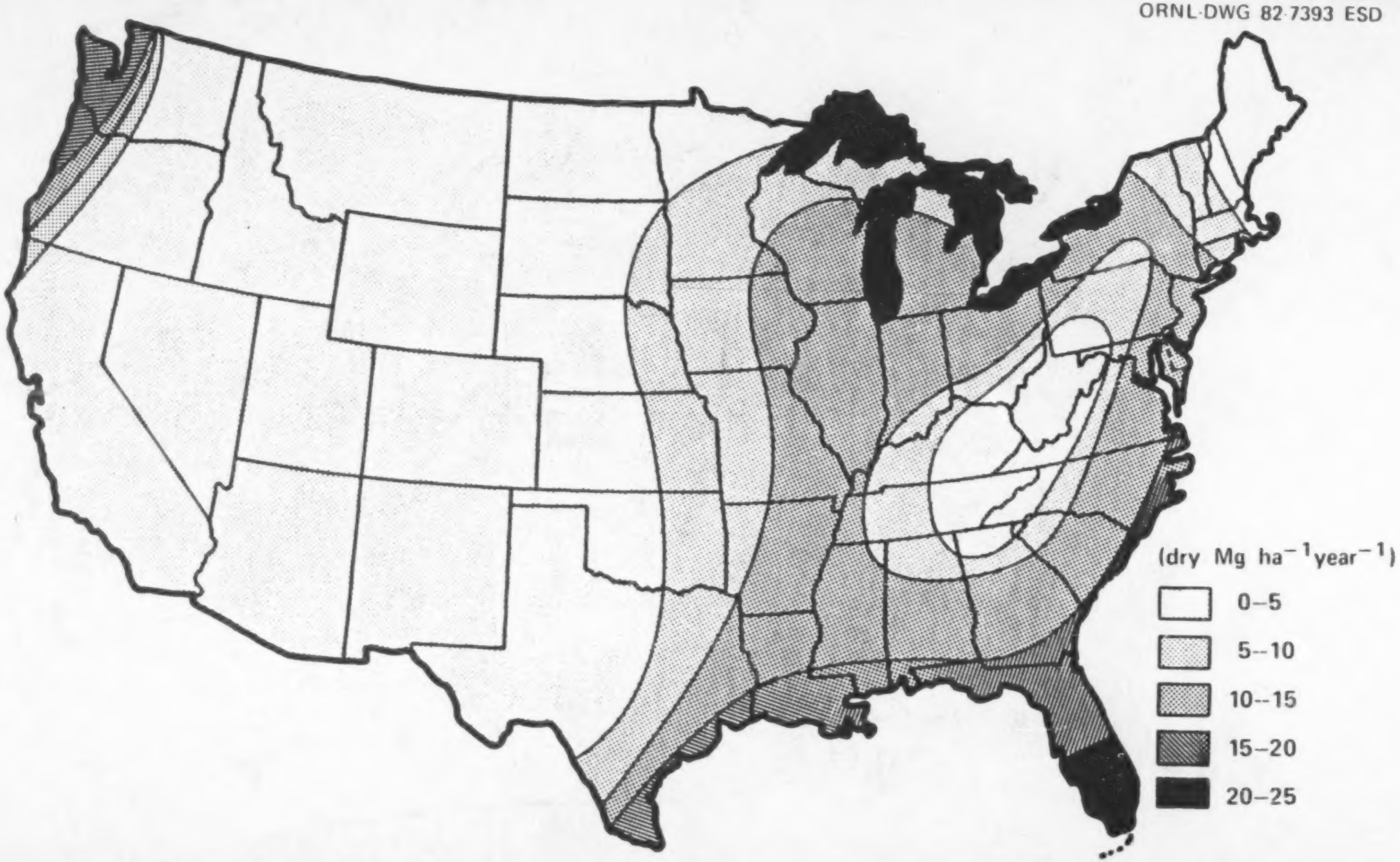

FIGURE 5.3 POSSIBLE PRODUCTIVITY RATES FOR LARGE-SCALE SHORT-ROTATION INTENSIVE SIVLICULTURE, ASSUMING IMPROVEMENTS FROM GENETICS, SPECIES SELECTION, AND MANAGEMENT PRACTICES.

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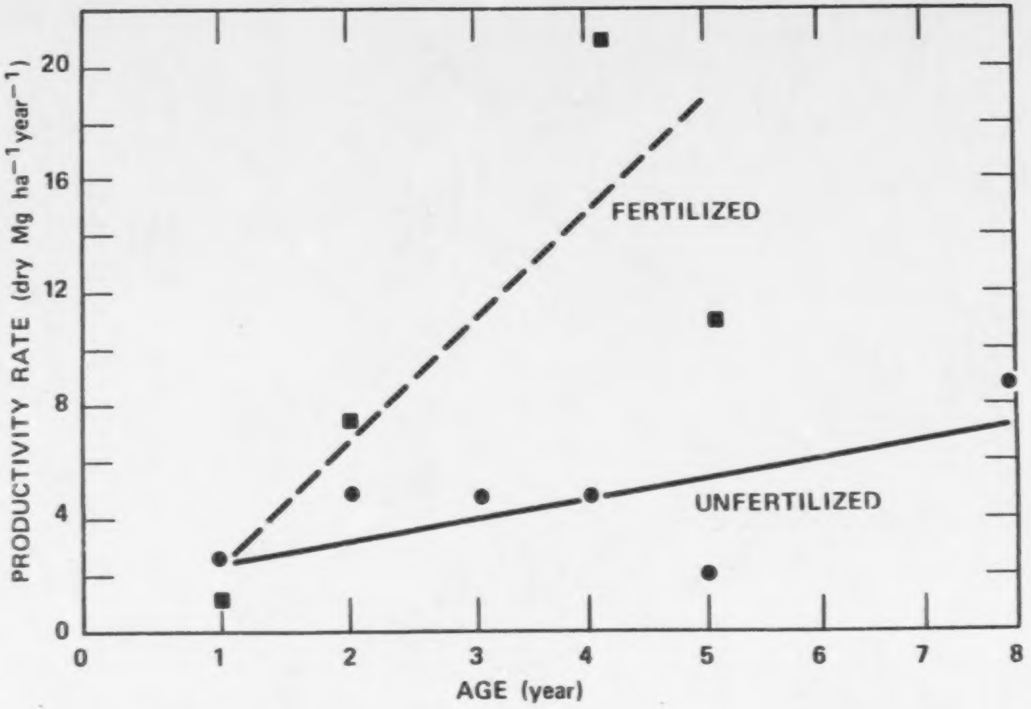

FIGURE 5.4 DATA FROM RESEARCH PROJECTS IN THE SHORT ROTATION WOODY CROPS PROGRAM, AVERAGED TO SHOW THE EFFECT OF FERTILIZER ON PRODUCTIVITY RATES.

# 6.0 ECONOMIC STUDIES

## 6.1 APPROACH

The major objective of the economic studies in the SRWCP is to increase the cost efficiencies of SRIC systems by integrating economic considerations into system design and research planning. Specific goals for this subject area include:

1. Identifying and defining the expenses associated with SRIC,
2. Determining the relative economic importance of the different components of SRIC systems,
3. Defining the critical range of variation for each major economic component of SRIC, and
4. Determining the site-specific revenue requirements for selected short-rotation woody biomass production systems.

This is the smallest and newest research area in the SRWCP. It was originally called "harvest, collection, transportation and storage of biomass," and still includes studies which are not in themselves economic analyses, but which are producing information needed to evaluate the economics of SRIC.

## 6.2 RESULTS AND IMPLICATIONS

Existing studies of SRIC economics have been specific to particular systems and sites and have been based on different sets of assumptions. However, some have included sensitivity analyses which help define the relative economic importance of the different components of SRIC systems. Since there have been very few studies to date, generalizations from the sensitivity analyses are probably more useful at this point than the specific projections of costs or profits.

The sensitivity analyses have consistently identified several factors as having the significant effects on the economic viability of the total system. In summary, the sensitivity analyses show:

(1) The costs of the entire system are most sensitive to land costs, harvesting costs, and productivity rates.

(2) The total cost of site preparation, planting, and management is significant, but changes in a single operation, except irrigation, generally make little difference in overall costs.

Table 6.1, derived from Mittelhauser Corporation's preliminary studies for the SRWCP, shows the results of a typical sensitivity analysis. Doubling management and equipment costs has little effect on the final price of the biomass product assuming all other items remain unchanged. Irrigation, on the other hand, is prohibitively expensive and requires that the price be raised 38% to cover its costs. Even if irrigation increased productivity by 20%, the price of biomass would have to be raised. Under these circumstances, irrigation would not pay for itself, however, if productivity could be increased by 20% by doubling management costs the price of the biomass could be reduced by roughly 5%. This change would be advantageous. SRWCP stand management research is now defining the relationships between investments in management (costs) and productivity (returns). Cost analysis, including extensive sensitivity analysis, will be used to develop economically efficient systems for using the available management practices in SRIC.

Existing cost studies underscore the limits of our current ability to make forecasts about SRIC. Our estimates for some of the most important factors are quite tentative, and we have almost no information about their variability. Land costs and product values can be estimated for specific situations with a degree of certainty, but they change across the country, and they become more uncertain when projected into the future. Harvesting costs are very important, but remain uncertain, since short-rotation harvesting systems have been proposed but none has yet been fully developed. Finally, the productivity rates achieved under an array of management systems are still variable and somewhat unclear, and we have very little information about productivity rates in coppice growth. More extensive data on coppice growth are still several years away, yet coppice regrowth is essential to the SRIC concept and must be considered in calculating SRIC costs.

We are now also beginning to estimate the risks associated with SRIC. Disease losses are being quantified for some species, but many of the species being considered for SRIC have never been grown under intensive management, and levels of possible loss to drought, temporary defoliation by insects, intermediate levels of plantlet survival, and poor sprouting success are completely unknown. These risks carry with them costs which must be incorporated into product prices, but which at this point can only be guessed.

In summary, the economic feasibility of short-rotation intensive culture depends on factors which are either very site specific, largely undefined, or both. If SRIC systems could be depended on to produce biomass at the levels now predicted by some experimental results, they would now economically be feasible in a number of places for a number of uses. However, many critical questions still remain. Those related to productivity and harvesting costs can be answered only with agricultural or silvicultural research of the type now found in the U.S. Department of Energy's Short Rotation Woody Crops Program. Others, particularly those related to end uses and product prices, will depend on technological developments in energy conversion, and on future wood and energy markets.

Table 6.1. A typical sensitivity analysis shows the effects of changing individual components of a proposed SRIC system

| Change from base case | Price impact (% change) |
|---|---|
| Doubling management costs | + 3.5 |
| Doubling equipment investment | + 2.5 |
| Adding irrigation system | + 38.0 |
| Changing land price from $815/ha | |
| to $2500/ha | + 25.4 |
| to $250/ha | - 7.8 |
| Increasing yield by 20% | - 9.2 |
| Decreasing yield by 20% | + 13.7 |

# 7.0 PROJECT SUMMARIES

## 7.1 SPECIES SELECTION PROJECT SUMMARIES

The University of Alaska is evaluating selected hardwood species for intensive biomass production on a range of sites in interior Alaska. Six native species, chosen in 1981, will be established on four sites throughout the state in 1982, and species/site interactions will be addressed. Genetic variation within a species will be examined to identify potential production improvements. In addition, selected species will be evaluated for chemical defenses against browsing by small mammals.

The University of Arizona is preparing a comprehensive literature review on woody plants in the semi-arid southwest to identify the most promising species for biomass production in this region. These species will be tested and selection will be based on productivity, site adaptability, ability to coppice, and resistance to pests and diseases. Field tests are being established in 1982 at three sites using *Prosopis* spp. and *Acacia* spp.

Michigan State University has been evaluating over 20 species for maximum biomass production on a range of sites since 1979. To date, several promising species (European black alder, hybrid poplar, and hybrid pine) have been identified and species/site interactions have been investigated. Guidelines for plantation establishment and management are being developed for cutover sites and old fields. Additional project emphasis is on genetic improvement and economic analyses.

Mississippi State University has measured genetic variation in biomass yields and disease resistance for sycamore in the Mid-South. Genetically superior seed sources and progenies have been identified for both biomass production and disease resistance. Productivity rates for seed sources planted at 9 $m^2$ (94 $ft^2$) per plant have been estimated at 5.5 dry Mg $ha^{-1}$ $year^{-1}$ (2.4 dry tons $acre^{-1}$ $year^{-1}$). Regression equations for predicting biomass from standing tree measurements have been developed and are being verified. A final report, due in June 1982, will summarize the three years of research in this project.

The USDA-Forest Service, Pacific Northwest Forest and Range Experiment Station is evaluating the response of red alder, a promising species for biomass production in the Pacific Northwest, to a variety of cultural practices. The genetic variability of the species, including broad geographic differences and variation in natural populations will be examined in this project, which started in 1981. Data will be collected on soil/site and productivity relationships to aid in site selection and prediction of relative yield for short-rotation alder plantations.

Utah State University, in a project now in its final year of research, has studied six native shrubs for biomass production on arid and semi-arid lands of the Southwest. Biotypes from a variety of native shrub populations were selected, propagated, and established on dryland sites. The following conclusions have resulted from this research: (1) biotypes of shrub species must be grown in areas where they are adapated; (2) further study is needed to determine the optimum rotation length; and (3) substantial productivity rates may be achieved (5.2 dry Mg $ha^{-1}$ $year^{-1}$ or 2.3 dry tons $acre^{-1}$ $year^{-1}$) from shrubs grown at close spacings and with minimal management on dryland sites.

The University of Vermont is evaluating the feasibility of short-rotation intensive culture of selected hardwood species on marginal agricultural lands in the Northeast. Since this project began in 1979, fifteen species of trees and seven clones of hybrid poplar have been screened for biomass production on a variety of sites throughout Vermont and New York. Various weed control methods, fertilizer levels, and management techniques are being evaluated. To date the most promising species are hybrid poplar and black locust with productivity rates of 10.4 dry Mg $ha^{-1}$ $year^{-1}$ (4.6 dry tons $acre^{-1}$ $year^{-1}$) and 10.8 dry Mg $ha^{-1}$ $year^{-1}$ (4.8 dry tons $acre^{-1}$ $year^{-1}$), respectively. Additional tasks include an assessment of land availability for biomass plantations and a study of the economic feasibility of short-rotation silviculture in the Northeast.

The University of Washington, in conjunction with Washington State University, is studying the genetic improvement of black cottonwood for biomass production. Fifty-five clones, 10,500 open-pollenated seedlings, and 3414 black cottonwood hybrids are being evaluated for rapid growth, disease resistance, and site adaptability. To date, a hybrid black cottonwood with eastern cottonwood is the most promising for short-rotation silviculture. After two growing seasons a productivity rate of 14.4 dry Mg $ha^{-1}$ $year^{-1}$ (6.3 dry tons $acre^{-1}$ $year^{-1}$) was achieved.

## 7.2 STAND MANAGEMENT PROJECT SUMMARIES

The University of Arkansas, in a cooperative study with the USDA-Forest Service and Georgia-Pacific Corporation, has characterized and quantified understory wood biomass in natural southern pine stands. Forty plots were established in two forest types (pine and pine-hardwood), two density classes (high and low), and two site classes (good and poor) in southern Arkansas and northern Louisiana. All sites have been harvested and the data has been collected. The average understory biomass production for all sites is 23.4 dry Mg $ha^{-1}$ (10.3 dry tons $acre^{-1}$) with a range of 2.2 to 57.6 dry Mg $ha^{-1}$ (0.97 to 25.3 dry tons $acre^{-1}$). The highest average yield, 32.1 dry Mg $ha^{-1}$ (14.1 dry tons $acre^{-1}$), was harvested from a poor, high density, predominantly pine site. The forthcoming final report will summarize project results and will address the long-term impact of periodic harvests of understory biomass on site productivity.

The University of Houston is evaluating the Chinese tallow tree as a species for intensive silviculture along the Gulf Coast. Stand establishment and cultural practices such as spacing, fertilization, and weed control are being studied. After three years of study it may be concluded that fertilizer application is critical to the rate of growth of young trees and that trees planted at closer spacings (0.3 $m^2$ or 4 $ft^2$ per tree) accumulated about two to four times the biomass of wider spacings (1.4 $m^2$ or 16 $ft^2$ per tree). Productivity in closely-spaced, fertilized plots is 8.06 dry Mg $ha^{-1}$ $year^{-1}$ (3.5 dry tons $acre^{-1}$ $year^{-1}$). Additional studies are emphasizing direct seeding techniques and coppicing practices. Genetic variability is being studied and superior individuals are being selected from natural populations for propagation and field planting.

The University of Illinois is evaluating the feasibility of using marginal agricultural lands for short-rotation woody biomass production. This project emphasizes sites typical of marginal agricultural lands that are currently non-productive. Seven hardwood species are being evaluated under a variety of spacings, rotation lengths, and cultural treatments. Results to date include preliminary information on growth under a variety of techniques for establishment and management of biomass plantations. This information will be incorporated into an economic analysis of biomass production systems when the experimental plantings have matured enough to produce the necessary data. Extensive herbicide trials have been conducted and appropriate treatments have been identified for various species and site types. This project will be completed in 1984.

Kansas State University is determining the biomass yields, financial and energy balances, and herbicide sensitivity of selected hardwood species in short-rotation intensive systems. After three growing seasons black locust, cottonwood, silver maple, and Siberian elm show rapid growth and a high rate of survival. From preliminary results it appears that a rotation length of five or more years and spacings of 1.8 to 2.4 m (6.0 to 8.0 ft) are desirable for short-rotation culture in this region. Several herbicides are effective in controlling the weed populations, but mechanical cultivation resulted in less tree mortality.

Michigan Technological University is determining the feasibility of converting existing pole-size maple stands (sugar maple and red maple) to short-rotation plantations using black locust as an interplanted species. Three forested sites, representing high, medium, and low productivity levels, were clearcut commercially. Plots were interplanted with black locust and fertilized with nitrogen, phosphorus, and potassium. Significant differences have been identified in stump sprout productivity by site, species, time of fertilizer application, and tree diameter. The symbiotic association of black locust with Rhizobium, the nitrogen-fixing bacterium, is being studied. Selected strains of the bacterium may enhance the productivity of black locust.

The BioEnergy Development Corporation in Hilo, Hawaii is evaluating Eucalyptus as a source of biomass fuel. BioEnergy has planted over 500 acres of Eucalyptus on the island of Hawaii. Approximately 30% of the acreage (150 acres) is being utilized for plantation establishment studies including fertilizer, herbicide, and spacing trials. The remaining acreage is being monitored for economic analysis and for future large-scale harvesting trials. The greatest growth, over 6.0 m (19.7 ft) in one year, has been achieved on fertilized sites. Productivity rates are being estimated at 40 dry Mg $ha^{-1}$ $year^{-1}$ (17.6 dry tons $acre^{-1}$). This project is scheduled for completion at the end of 1983.

The University of Florida is evaluating seven native and exotic woody species for biomass production. This is an interdisciplinary research effort, which started in 1979 and is scheduled to end in 1983, includes: assessment of land availability; intraspecific genetic selection; species screening; evaluation of cultural treatments and management regimes; and economic analysis of short-rotation intensive silviculture. A statewide survey of land availability and quality has been completed. To date, eight sites have been planted throughout the state and data on genetic improvement, fertilizer responses, growth rates, and water use is being collected. Preliminary estimates of biomass productivity by selected Eucalyptus progenies exceed 13.0 dry Mg $ha^{-1}$ $year^{-1}$ (5.7 dry tons $acre^{-1}$ $year^{-1}$) and with the addition of high nitrogen fertilizers productivity may exceed 20.0 dry Mg $ha^{-1}$ $year^{-1}$ (8.8 dry tons $acre^{-1}$ $year^{-1}$) on selected sites.

The University of Georgia (W. L. Nutter, Principal Investigator) is evaluating biomass production of five hardwood species in short-rotation plantations irrigated with municipal sewage effluent. This project is a cooperative effort between the university and the Clayton County (Georgia) Water Authority, which operates the largest land treatment system in the United States devoted to forest production. The goal of this project is to provide information regarding species establishment and suitability for large-scale plantations at land treatment sites. The project began in 1981 and is scheduled to end in 1986.

The University of Georgia (K. Steinbeck, Principal Investigator) is investigating means of increasing the biomass production in short-rotation intensive systems through species admixtures, fertilization, and cultural practices. In addition, techniques for cloning genetically superior hardwoods are being developed. Two plantations of fifty acres each have been established, one in the Coastal Plain and one in the Piedmont of Georgia. Height growth of 6.0 m (19.7 ft) has been achieved after three growing seasons. The mass cloning program using tissue culture techniques has produced fully rooted plantlets with survival rates of over 90%. Harvesting equipment has been obtained and 4-year-old stands will be harvested in the winter of 1981-1982.

The University of Minnesota is evaluating the potential of peatland areas for woody biomass production. The principal objectives of this project are as follows: (1) evaluate the productivity of natural stands, (2) develop propagation techniques for exotic and native willows and alders, (3) establish a nursery on wetland soils, (4) establish biomass plantations on wetland soils to evaluate the yield of selected clones, and (5) determine the potential of wetland soils for woody biomass production. Two objectives have been completed; the determination of natural stand productivity and the evaluation of wetland potential for woody biomass production. Over 60,000 willow plantlets have been propagated via tissue culture. An additional 15,000 willows have been propagated by cuttings, including several species which have been very productive in European studies. A 1 ha (2.5 acres) nursery and 5 ha (12.5 acres) of field plots have been established using promising willow and alder varieties.

North Carolina State University is screening hardwood tree species and evaluating silvicultural systems for woody biomass production in the Southeast. This research project has been greatly enhanced by cooperative efforts within the North Carolina State University Hardwood Research Cooperative, which is composed of state agencies and 18 forest industries. The cooperative members provide land for field sites, technical support, and equipment. Four plantations have been established to evaluate species/site relationships, spacing, coppicing, and rotation age. Conclusions to date are: (1) sweetgum is the most adaptable hardwood tested, (2) hardwoods must receive intensive care until well established for acceptable growth and development, and (3) species/site interactions must be considered.

The Packaging Corporation of America (PCA), a forest products company in Filer City, Michigan, is evaluating woody biomass production of large-scale hybrid poplar plantations. To date, PCA is the only large-scale planter of intensive-cultured hardwoods in the Great Lakes region. Over 1.5 million hybrid poplars have been planted on 1200 ha (3000 acres) for intensive forest management. The existing plantations will be used to determine the economics and productivity rates of large-scale short rotation plantations. This project will also emphasize the following areas of research: (1) development of soil/site/yield guidelines; (2) evaluation of plantation establishment techniques, including herbicide application; (3) evaluation of plantation management strategies, including pest management; (4) evaluation of poplar nursery management techniques; and (5) evaluation of the economics of plantation establishment and management techniques.

The Pennsylvania State University (P. R. Blankenhorn, Principal Investigator) is evaluating the productivity of short-rotation hybrid poplar under four management strategies (control, irrigation, fertilization, and irrigation/fertilization). After two growing seasons a maximum height of 2.9 m (9.7 ft) was achieved under the irrigation/fertilization treatment. Data are being collected on the energy and economic inputs needed to operate and maintain the plantation under each management strategy. These data will be analyzed using a linear programming model which will identify the most efficient management strategies for attaining a maximum net energy or financial output.

The Pennsylvania State University (W. E. Sopper, Principal Investigator), now in its final year, has evaluated the effect of municipal wastewater irrigation on biomass production in hybrid poplar plantations. An economic analysis of using wastewater as a substitute for inorganic fertilizer is underway. Results obtained to date indicate that wastewater irrigation significantly increased diameter and total height growth of hybrid poplar. Furthermore, total woody biomass production was more than doubled by wastewater irrigation after three years of growth. A forthcoming final report will summarize the four years of research from this project.

Seattle City Light, a municipal utility in Seattle, Washington is evaluating various cultural treatments of red alder and black cottonwood for optimum woody biomass production in the Pacific Northwest. Two research plantations, 10 acres each, were established in 1979. Data are being collected on growth response to spacing, irrigation, fertilization, cultivation, and species mixture. Technical experts are being consulted on equipment, economics, planting stock procurement, and environmental impacts. This project will be completed in 1983.

Texas A&I University in Kingsville, Texas is investigating production of woody biofuels from mesquite. Mesquite is a leguminous woody shrub indigenous to tropical and subtropical arid and semi-arid regions. This project is using clonal stock from 20 shrubs which were previously identified as promising for woody biomass production. The goal of this project is to utilize these high producing strains for cost-effective commercial biomass farms. Research efforts include determination of biomass production, collection of additional plant material from unusual sources and origins, and refinement of tissue culture techniques and propagation methods.

USDA-Forest Service, North Central Forest Experiment Station, in the final project year, has developed a management program for establishment of large-scale poplar plantations. The establishment period, defined as the first three growing seasons, is the most critical period for large-scale plantations. Investigators in this project have identified optimal methods for site preparation, planting, and weed control. Selection of planting materials and initiation of pest management strategies are also being studied. The percentage of successful plantations (those with greater than 75% survival) has risen from 15% in 1977 to 95% in 1980. A forthcoming final report will summarize the five years of research from this project.

## 7.3 ECONOMIC STUDIES PROJECT SUMMARIES

The Biosys Corporation of McLean, Virginia is evaluating the availability of land for short-rotation biomass plantations in the Western Great Lakes Region. This project will address the following issues: (1) the potential land resource available for biomass plantations, (2) major issues in land competition, (3) the types of sites available for biomass plantations, and (4) the location of potential sites. A final report describing the results of this project will be compiled by July 1982.

Mathtech, Inc. of Princeton, New Jersey has analyzed and applied ten scenarios to an optimization harvesting model previously developed for the Biomass Energy Systems Division. The model accounts for the processes of shearing, chipping, collecting, transporting, storing, and processing of woody biomass. The ten scenarios involved mode of operation and terrain configuration. Drying characteristics of the harvested biomass was incorporated into the model. A final report describing the analyses of the biomass harvesting model will be completed early in 1982.

Mittelhauser Corporation of Downers Grove, Illinois has developed an integrated computer program that will measure woody biomass product price sensitivities to various modes and intensities of silvicultural management practices. The model incorporates the costs of all relevant aspects of short-rotation woody biomass production including: land purchase or lease, establishment, development, harvesting, and storage operations. A final report that describes the model and a series of sensitivity analyses will be completed by March 1982.

Virginia Polytechnic Institute and State University is completing the conceptual design of a harvesting system to sever, collect, transport, and process woody material from short-rotation energy plantations. The harvesting system will offer flexibility in harvestable tree size, operable terrain, and road spacing. The system will be able to handle single stems from a seedling planting and multiple stems from coppice development. In addition, the harvester will use base carriers that may be readily adaptable to spraying, fertilization, site preparation, and other stand management activities. Research efforts to date include the evaluation of severance devices and the design of a "tree grabber." An existing skidder is being modified to serve as a base machine for the harvesting system.

Mr. HEITOWIT. Mr. John Stinson, manager, Biomass Fuels Program for TVA.

Mr. STINSON. I am pleased to appear before you to talk about the TVA's biomass fuels program and needs for further research, development and demonstration in the renewable energy area. I will enter my written testimony in the record and I would like to make a couple of points—one that is not in the written testimony.

We have facilities throughout the Tennessee Valley for biomass studies. Our biomass research activities are located in Muscle Shoals, Alabama. You may be interested in knowing that a processes developed by TVA result in the production of over three-fourths of all the chemical fertilizers produced in the United States. In other words, over three-fourths of the fertilizer produced is made by processes developed by TVA at Muscle Shoals. This illustrates the scientific type personnel at the facilities that we have available there.

We feel that our experience in scaling up laboratory research that can be used by industries is an especially valuable asset.

I agree with Mr. Shirley's comments on the use of wood. As in the Tennessee Valley, our Nation has a vast supply of renewable resources such as wood. We have a large amount of under utilized hard woods and under utilized soft woods.

I feel emphasis on utilization is important. Also, there is a need to see that wood can be effectively converted to liquid fuel. Our petroleum reserves are dwindling. Our Nation should make every effort to avoid a repeat of the problems created with the energy crisis in the 1970's.

Putting those two together, an important need, therefore, is development of an efficient process for converting our abundant supply of wood to a liquid fuel such as ethanol. This is the most important program in TVA's biomass fuels program.

We know from our extensive research and development experience that laboratory results can not be used directly for the building of commercial plants. Data from larger scale testing must be obtained in order to obtain effective scale up with reasonable risk.

The very important point is that without engineering information, industry could not afford to invest. The risk involved in the scale-up process is too great.

I wish to thank you for the time. I made my comments short, as you requested.

[The prepared statement of John Stinson follows:]

Field Hearing
Energy Development and Applications Subcommittee
Committee on Science and Technology
U.S. House of Representatives

RENEWABLE ENERGY IN THE EIGHTIES:
NEEDS FOR FURTHER RESEARCH, DEVELOPMENT AND DEMONSTRATION

Knoxville, Tennessee
May 28, 1982

Testimony by

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Mr. Chairman, Committee Members, I am pleased to appear before this Committee to summarize TVA's Biomass Fuels Program and to talk about needs for further research, development, and demonstration in the renewable energy area.

TVA's biomass research activities are centered at its National Fertilizer Development Center in Muscle Shoals, Alabama. At other locations in the Valley we have facilities for providing complementary expertise on forestry management and harvesting and wood combustion systems. The fact that about three-fourths of all chemical fertilizers presently used in commercial agriculture in the United States is produced by processes developed at the Center illustrates TVA's practical research and development capabilities. TVA has excellent scientific laboratory facilities, the expertise of a multidisciplinary staff, and engineering experience to transform concepts into practical applications. The experience in scaling up laboratory research is an especially valuable asset. The proven success of our chemical fertilizer programs, the available facilities, and the existing expertise provide a sound foundation for achieving concrete and usable results, not just paper studies. In addition, TVA has a history of work in biomass-related activities and a record of cooperation and coordination with other agencies as exemplified by work over the past three decades with the U.S. Department of Agriculture.

Our program is designed to develop information for more effective use of Valley resources--both woody and agricultural biomass. The Valley has an abundance of underutilized hardwood forest reserves. More than half of the region's total area is in forests. Hardwoods account for over 80% of the forest inventory and annual growth is nearly three times current harvest. Hardwood prices are depressed to the extent that good management is often not practiced. Even without silviculture, 30 million tons of hardwood is available annually for energy use. This is sufficient to supply about one-third of the energy currently used in industrial applications and also to produce annually about 1 billion gallons of ethanol. The annual Valley gasoline consumption is estimated to be about 4 billion gallons.

As in the Tennessee Valley, our Nation's most abundant renewable biomass source is wood, and we have a vast supply of underutilized wood sources, such as hardwoods and wood wastes. So emphasis on utilization of wood is of prime importance. Also, there is a need to ensure that wood can be effectively converted to a liquid fuel such as ethanol. Our petroleum reserves are dwindling, and our Nation should make every effort to avoid a repeat of the problems created with the oil embargo of the 1970s. A most important need therefore is development of an efficient process for conversion of wood to ethanol. This is the most important project in the TVA Biomass Fuels Program. A prime objective is research to develop an effective acid hydrolysis process for conversion of woody biomass to ethanol.

The information developed, however, will have nationwide adaptability. Hardwoods extend into the Appalachian area, up the east coast, and are in the Ozark area. The information we develop also will be suitable for use with the softwood trees of which our Nation has an abundance, particularly in the far northwestern section.

Our study on production of ethanol from wood is being carried out in cooperation with the Wisconsin Forest Products Laboratory of the U.S. Department of Agriculture. The laboratory is doing fundamental wood chemistry research, and TVA is carrying out the larger scale studies that are necessary for proper development. The process under study is a modification of one developed by the two organizations many years ago and which is, as we understand, the basis for the USSR's industry for production of ethanol from wood. Early TVA results are already quite encouraging and indicate that increased alcohol yields will result. Our goal is to increase the alcohol yield per ton of wood from the current 40 to 50 gallons to a level of 70 to 80 gallons. In addition, lower investment and operating costs are anticipated.

We know from our extensive research and development experience that laboratory process results cannot be used directly for the building of commercial plants. Data from larger scale testing must be obtained in order to achieve effective scaleup with reasonable risk. Without engineering information, industry cannot afford to invest because the risk involved in scaleup of a process is too great relative to the potential payoff.

Support for this research effort should continue until the engineering information required by industry is obtained.

Another route for production of ethanol from wood is by the use of enzymes. This route, which is being studied by others including private industry, needs research support. Before we completely settled on the acid hydrolysis route, we held many discussions with experts including those in enzymatic hydrolysis. It was generally agreed that the acid hydrolysis route could be developed more rapidly.

Methanol also can be produced from wood and research should be continued on its production. Our budget is small, and since many others were working in this area we did not include this in our program.

We encourage private industry and nonprofit organizations to utilize wood in direct combustion and carry out engineering studies to assist potential users. Construction on the first unit to which assistance was given was started in February 1981 and the unit is now in operation. Since then an additional 17 units are under construction or have been completed.

To derive the biomass statistics necessary for use by private industry, detailed supply and use data for each Valley county are being obtained. In addition, we are holding workshops to inform the Valley's forest industry of good management and harvesting practices.

The Valley's potential for producing renewable fuels from agriculture is not as great as from wood. The region is a net importer of feed grains. However, as much as 2 million acres of underutilized marginal lands exist on which biomass crops may be grown to produce feedstock for ethanol production.

In cooperation with the Department of Energy, we are carrying out a study on the development of technologies for on-farm production of ethanol from fermentable carbohydrate feedstocks that may be grown on this marginal land. A 10-gallon-per-hour test unit is being operated to obtain benchmark data.

We have made a strong effort to coordinate our program with other Federal agencies as well as with State agencies and private companies. In fact, many of our activities are carried out in cooperation with other organizations. It has been our experience that research and development programs are most effective when well coordinated with all parties involved. As part of this effort, TVA will hold a conference this July to which researchers in the Southeast will be invited. Hopefully we can, in this manner, be a catalyst to promote closer coordination in biomass research in the area.

Close liaison is planned with each of the States in the Valley. We have met with State officials and others from Mississippi and have assisted the State in an assessment of its biomass capabilities. A wood-energy group will be formed to advise industry; we have agreed to be a member of this group. Our meeting with Alabama officials will be held soon. Meanwhile, we are part of a group advising Alabama industry on potential biomass-type projects.

I wish to thank this committee for allowing the time for me to summarize TVA's Biomass Fuels Program and to offer some comments on future needs.

Mr. HEITOWIT. We will have questions.

Mr. FRANKEL. Mr. Shirley said explicitly and Mr. Stinson seemed to imply that production related things are not important because we have such abundant existing wood supply and you are stressing a production-oriented program. Would you like to explain that?

Mr. RANNEY. I would be glad to. I don't see it as a discrepancy at all. The existing wood resources in this country are the great biomass resources we have available for energy. This wood is unevenly distributed around the country. In some places you can't always get to it the way we would like to and you can't get it sometimes all year round.

The productivity rate, if we are looking at a long term supply of wood, is not known on a lot of these forests. We don't know what the real productivity rate is that will permit us to go back year after year tapping these supplies.

So, looking in the longer run at our wood supplies, how to stablize them over the long term, and also getting wood to facilities, to these installations for conversion, wood is very bulky and it is hard and expensive to transport. If we could move wood when we grow it, that gives us that much more of an added supply close by than we can count on. And what I am advocating, the short rotation intensive culture research, is that we go toward a balanced program to make this existing wood resource as usable as we can.

That is, we have something to back it up in case some problems occur for example in the transport and that sort of thing. Short rotation intensive culture is a supplement to it, but it is the area that we have the least knowledge about. It requires the newest technologies that are not developed yet and this is why I am saying Federal funding should be directed in this way.

Mr. FRANKEL. Mr. Stinson, in the conversion technology area, how far does the Government have to take the development and demonstration process before the private sector can pick it up? Do we stop at the bench scale level or the process development unit level or do we have to go to a small scale demonstration unit before the risks are sufficiently well known for the private sector to commercialize it on their own?

Mr. STINSON. Let me amplify just a little my answer to you so I can get in another point I want to make. There are four steps in the conversion from the concept of an idea to commercialization. The first is basic research.

Let's take the forests or wood as an example.

We normally think of wood as something you build something out of and you chop it up. Wood is a feedstock, an infinite number of chemical compounds can be made from wood. We need really basic research in our universities. I think, that there is nothing wrong with having biomass program in the univeristies. For example, a degree could be given for biomass engineers or biomass scientists. There is no teling how far we could go or really what products could be produced if we had a good basic research program.

The second step is bench scale studies. This is combining basic research studies into a practical process, really seeing if one can be developed.

I guess, too, I am talking about a pyramid effect. You may have a lot of basic research studies and less bench scale studies and eventually you are going to arrive with one or two processes that can be commercialized.

In the bench scale studies you can determine if you have a practical process. The basic research studies may be necessarily concerned with pure materials. An example of that is the conversion of a hemicellulose to alcohol. There are a lot of studies going on with pure materials. There are very few studies going on with materials that you actually get when you produce cellulose from wood. This can be studied.

The next step is pilot plant studies which I feel are very important and the fourth step is commercialization. I feel in the biomass area that Government should go through the pilot plan step. It has been our experience that industry is only going to step in and develop a process when they know it is going to be economical, when they have what we call the proper scale-up factor.

If you divide the reduction rate of a commercial unit by the production rate of a pilot plant (say you run a one-ton per hour pilot plant and you run a 20-ton per hour commercial unit) it gives you a scale of 20. Industry is very reluctant to go much higher than the scale-up factors of 20. They found it is just not economical to do so. They are really developing a process for somebody else to use. We have been very successful at TVA in carrying out studies through the pilot plant step defining really where the problems are, and in providing the engineering information for the two industries.

I don't think the Government has a place in commercialization or large-scale demonstrations, but I do think we have a place up to the pilot plant scale.

Mr. FRANKEL. In 1978 or 1979 the Department of Energy split off its alcohol fuels program from the biomass technology program. Does that split make sense from an R&D perspective and would it be advantageous to re-combine the two programs?

Mr. STINSON. I don't know that I am qualified to answer that question. We have worked extensively with the Office of Alcohol Fuels, but not with the others.

Mr. FRANKEL. I was just thinking, your program is a biomass fuels program, and part of the program is alcohol fuels?

Mr. **Stinson**. Yes.

Mr. **Frankel**. From a fuels research point of view, can you actually separate out alcohol fuels from other forms of conversion?

Mr. **Stinson**. Yes. We have no problem. We work very aggressively with DOE's office.

We have two programs we hope to carry out in the future and we are carrying out one right now.

Mr. **Frankel**. As you view the DOE's alcohol fuel program, do you think that DOE has struck a proper balance between lignocellulose and other feedstocks, between chemical and biological conversion processes and between ethanol and methanol?

Mr. **Stinson**. No; I don't think enough attention is given to lignocellulose conversion to alcohol.

I want to repeat myself. I think we need to avoid a potential problem like we had back in the 1970's and I think we need to get the information available for the future while we have the opportunity. If we have a crisis on hand, that is no time to start.

Mr. **Frankel**. I have no further questions.

Mr. **Heitowit**. Dan Steinway?

Mr. **Steinway**. Thank you, Mr. Chairman.

Mr. Stinson, the committee has heard a lot of testimony on the merits of acid versus enzymatic hydrolysis. Can you tell us why you chose to go the acid hydrolysis route, the pros and cons of it and areas where you think we might want to do some research in the future?

Mr. **Stinson**. Yes; we have a natural interest in the acid hydrolysis program. You may know that TVA was instrumental along with the Department of Agriculture in refining the original German process for the conversion of wood to ethanol. This process is practiced in the U.S.S.R. with some 44 plants. It is an acid hydrolysis process. When we began our program, we were very much interested in seeing if we could improve that process. Working with people from the Madison, Wis., plant and with some Swedish scientists, we defined some improvements we could make in that process. But before we went on with that, we traveled extensively. We have sent people to some eight countries throughout the world and we have traveled ourselves extensively through this country talking to people experienced in enzymatic hydrolysis and in acid hydrolysis. I guess of the 30 people I talked to, I only talked to 1 individual that thought enzymatic hydrolysis really had much of a chance in the next 5- to 10-year period.

People that are most experienced in that, I think, are in the Nadick Laboratory in Massachusetts and they say quite frankly that the acid hydrolysis is best; that had a strong influence.

When we talk to the people in enzymatic hydrolysis, we run into a lot of optimism. But when we actually sat down and talked to them, about how the process should be carried out, we found most studies were made in test tubes and their economic viability is on selling lignin byproduct at a very, very high price. That is the only way they can come out economically.

Mr. **Steinway**. At what scale do you think there is justification for Federal support for the acid hydrolysis route before the industry will take it over by themselves.

Mr. **Stinson**. About 25 to 50 tons of wood per day.

Mr. STEINWAY. Where are you now?

Mr. STINSON. Right now we are at laboratory scale. We hope to build, eventually about a 200 or 300 pound a day unit. We are 2 or 3 years away from an improved process.

Let me give you some examples of differences between what you could have today and what we hope to have in the future. Today you would have a process that is about 25 percent efficient. It has a lot of byproducts that are not really produced in this country. You have very, very expensive processes. The process that we have in mind, and the one which is really our laboratory tests indicates it is very, very promising, would have an efficiency of around 70 to 72 percent. It would have very, very short retention times. The alcohol yield per ton would be essentially doubled and since the retention time is shorter, the cost would be a lot lower.

We are energy self-sufficient in the process. We burn the bark that we get from the wood and a little bit of the lignin byproduct, so that means you could locate your plant anyplace you wanted. The current plant in Russia requires sawdust; it is a very expensive process to grind wood to fine size if you don't have wood waste.

Mr. STEINWAY. I just have one further question, Mr. Chairman. There have been many players involved in the forest production part of the biomass energy production program. The committee has heard about the USDA program. SERI has been involved, DOE has been involved. In taking back recommendations to our committee in Washington we must provide for an efficient management of all these players. Do you have any thoughts or any comments on a way to streamline the management of an effective woody crops program? Do you think USDA should manage it themselves or work closely with DOE or should DOE be responsible for direct management of the program?

Mr. RANNEY. I have been dealing with that question for a long time in the position that I have been in and it is difficult to come up with an answer. My observations have been that indeed a centralized national program really helps speed the research along.

USDA has the experts in forest technologies, the recognized ones. They have very good contacts with the wood industry and are very capable, but I am concerned about their interests in recognizing the importance of energy among the alternatives in wood.

It has been a concern of mine all along. I am not saying they don't, but it is not the kind of priority thing that the Department of Energy looks at.

I don't know how to integrate the two, Department of Energy and Department of Agriculture Forest Service more than what they are doing right now, but there certainly is more that is needed. I don't have a good recommendation because I have looked at a lot of alternatives and I still haven't found a good one.

Mr. HEITOWIT. Are there any further questions?

Mr. DUGAN. Dr. Ranney, our subcommittee and Mrs. Bouquard have a keen interest in TVA's programs and I have a budget question for you.

As you know, the Department of Energy's request in biomass was only, I gather, $7,605,000.

The full committee chairman, Mr. Fuqua, has made a recommendation to the Appropriations Committee which Mrs. Bouquard supports that would fund that program at $20,500,000 for 1983.

My question is how will the personnel slots in your group be affected if you have to go with the 1983 budget request versus the committee recommendations?

Mr. RANNEY. Going with the 1983 budget request, our program would be entirely terminated.

There would be no money to schedule for the 1983 fiscal year. We would have to shut down all projects and most of them are multiyear projects, 6 to 7 to 8 years. Since we are dealing with plants and the growing of them in the field, we would have to cut those off prematurely, every one of them. We would have to close things down. With the committee request, it would allow research to continue at about the level it is now. As it is now, we cut things to bare bones to keep the research going and we can do that if level funding is requested for the biomass program in the Department of Energy.

Mr. DUGAN. What is your funding, for instance, in feedstock development? Are you funded entirely under the woody crops subprogram?

Mr. RANNEY. Well, there are several programs funded through this biomass program. The herbaceous——

Mr. DUGAN. I have a list of those here, yes.

Mr. RANNEY. Our funding would be approximately $3 million a year and that is enough to keep us going.

Mr. DUGAN. If you get zero funding for 1983, what does that mean in terms of people?

Mr. RANNEY. Almost all of the projects, most of the university and some for industry in which they are cost sharing, that would be stopped. Universities and graduate students and researchers with the Forest Service and industry would have to find new work somewhere else.

Mr. DUGAN. Are there any laboratory people affected in that case?

Mr. RANNEY. Me and about two or three other people. The laboratory would not be affected very much at all.

Mr. DUGAN. So you are chiefly managing the projects?

Mr. RANNEY. Our mission is the technical management of the work and coordinating and providing for the integration of the results.

Mr. DUGAN. I see.

I have one additional question, Mr. Chairman, which I'd like to ask John Stinson.

John, is there a significant interaction between the people involved in your biomass program and the DOE people in terms of exchange of information? Is there any cost sharing, et cetera?

Mr. STINSON. Our main project is in the production of wood. In that area there is very little interaction. We have had a lot of contacts with DOE, but I'm sorry to say there is very little interaction.

I guess the second most important project that we are in is the production of on-the-farm facilities for producing ethanol from crops that may be grown on our marginal land, and in that area there is extensive cooperation. We are in phase III of a three-phase program in that area, and a large part of the money is coming from DOE, particularly in phase III.

There are two other areas in which we are working with the DOE. One is what we call phase IV. There has been developed at Purdue a process for the acid hydrolisis of cellulosing nonwood materials by Dr. Tsao, who incidentally used to work with the TVA. We have been approached by DOE to carry out pilot plant studies on that. That has been signed off, as I understand it, by Jim Sterns in the procurement office to be processed into contract form.

Another area which we are working in—we were approached by DOE, by the way, on that as you know—is the loan guarantee program. We were approached as to when we could provide technicl assistance to them in the construction of these plants in this program. We agreed to do so, and I got the word 2 days ago that that contract perhaps will be in my office today. If it is not this week it will be very shortly. That will be a multiyear contract.

Mr. DUGAN. Is there any attempt, though, to sit down and comprehensively try to make the programs mutually complementary in a planning stage before the budget cycle, or anything like that?

Mr. STINSON. No, I'll be real frank with you. We went through a very, very strong effort to do so, even taking board members to DOE offices and talking to them and even participating in review programs at DOE. But, no, we did not plan mutual programs.

I'm not criticizing Mr. Sterns. But in our main program of ethanol from wood I think DOE thought we were just, quite frankly, trying to get money from them, and that wasn't the situation at all. We are trying to cooperate and we do make a very aggressive effort to talk with various agencies. I wish I could say it was better.

Mr. DUGAN. Thank you very much.

Mr. HEITOWIT. Gene Frankel has a question.

Mr. FRANKEL. I want to follow up on Dr. Dugan's question. I have been asked by some people in Congress whether or not there are parts of the DOE biomass programs that could be assumed by TVA, and I was wondering if you have any thoughts on that issue.

Mr. STINSON. I'm sorry, Gene, I just can't hear you.

Mr. FRANKEL. I have been asked whether or not there are parts of the existing DOE biomass technology program that could be picked up by TVA. Can you think of any particular areas where you would have some strength to assume some of that work?

Mr. STINSON. I still did not quite understand the last part of what you said, but let me assume. Yes, sir, we would very much like to do so. I think we have the capabilities of doing so. We have not discussed it, obviously, with anybody. Did you ask what areas that would be?

Mr. FRANKEL. Yes, sir.

Mr. STINSON. Certainly, I think in ethanol production by acid hydrocysis what little is done by DOE could be done by us, using either woody biomass or agricultural biomass. Some of the other programs, like gasification studies could be carried out by TVA. We have a tremendous capability for many types of experimental studies.

I wish you could come down and see our facilities, Gene. We have some 900 scientists of all disciplines there, and we are willing to take on just about anything except we do not have many really experienced in the microbiology area. We only have one microbiologist.

The use of enzymes is an area where we really don't have much experience. But when you come to the area of engineering experience, I think we are just as good as anyone.

Mr. FRANKEL. Conversion technology?

Mr. STINSON. Yes, sir, we would be very receptive to that.

Mr. FRANKEL. You may hear from us again on that.

Mr. STINSON. Thank you; we would enjoy doing so.

Mr. HEITOWIT. I have one question. Listening to the testimony this afternoon, some of it having to do with direct combustion and conversion, et cetera, a few witnesses mentioned in passing the need to consider environmental issues, but at this time I'd like to get specific.

Are there any particularly difficult environmental problems associated with production, conversion, or direct combustion that you think require greater emphasis in R&D, from your point of view?

Mr. RANNEY. I'll talk about the biomass feedstock production aspect first. Yes, sir, there are some particular environmental concerns. They deal with really the most technologically intensive management strategies. As far as nutrient removal and the increased use of fertilizers and pesticides, we don't know what the long-term effect on productivity of the soils is going to be. There are very few studies examining this.

There is also concern with utilizing existing forest stands that we don't know for sure that there is going to be an impact on productivity over the long term, but there might be. Indications are that on many sites if we go with a 50-year rotation in harvest or longer, probably there wouldn't be any severe environmental effects, but it depends on the kinds of sites we are talking about. If we are talking about some of these hardwood stands that occur all over the Southeast and the Northeast, we are not too sure what the effect is going to be.

There is another environmental concern, if I can include some social aspects in environment, on just what the land-use trade-offs and resource trade-offs are going to be between wood production, agricultural production for energy and agricultural production for food, those sorts of things.

They really have not been very well addressed because we don't know very well what the economics are of a lot of these energy strategies for biomass production. So any evaluations we have so far are very unclear, and this needs a lot of attention.

I really don't see that there is going to be too much conflict between production of wood feedstocks and agriculture, but there will be at some locations. It will be site specific.

Mr. STINSON. I'd like to comment a little on the conversion. We have a very aggressive attitude toward environmental studies. We have a committee right that is multidisciplinary studying to determine what environmental studies should be carried out.

If you take, for example, the production of ethanol from wood, since you can make an infinite number of chemical compounds from wood, you have a very, very large possibility of small amounts of many organic chemicals being in the gases and so forth. That is why it is extremely important to know exactly what you are doing and know what compounds are formed. We are not quite there yet. We can only now postulate some of the byproduct compounds that we will get. Those that we postulate we are not really worried about, but those may not be the ones that we produce. Research is going to have to tell us exactly what is going on.

In the direct combustion, yes, sir, I think there are some problems. We ran into problems in the valley having too many residential stoves in a particular area, and we are carrying out studies to measure the off gases and to know what is present.

Mr. BUFFINGTON. Mr. Heitowit, you talked earlier about priorities for research. Let me expand on one thing that Mr. Stinson just said.

The use of wood in direct combusion for home heating had become very, very popular in the Southeast and the Northeast and many other areas of the United States. This is the area that I guess we have devoted the least amount of technological research and development to have any of the biomass uses, and yet it is one of the most widely spreading uses of biomass in the United States.

As Jack mentioned, we are having air pollution effects from it, and we are having safety and health effects. Basically it's because we are using a very, very simple technology but it is polluting. I think one area we failed to devote any technology to is improving that type of heating technology. There is technology available. There are concepts available that would make it much safer and much less polluting heating devices for home, residential and larger heating applications.

I think that is an area that we need to stimulate research and development in some area. This market is so great, there has been no incentive to do any improved technology development in that area.

Mr. HEITOWIT. Thank you, Mr. Buffington.

Gene Frankel has one last question and then we will close.

Mr. FRANKEL. I would like to get in one last question on the DOE program. It has a part devoted to production which includes aquatic systems, herbaceous systems and woody crops, and then there is another part that's devoted to conversion, biochemical, thermochemical, and biological nitrogen production. Do you feel that that covers the ground pretty much? Is there something missing or is there something there that should not be in those six activities divided into two areas that I've mentioned?

Mr. STINSON. Gene, it's very difficult to hear you.

We cover a lot more than two areas. We have two main areas: one is woody biomass and the other is agricultural biomass. In each area we have projects underway identifying the resource and production, harvesting, transportation. Then we have conversion studies and economic studies underway, as well as marketing and environmental studies. I've only talked about some of them.

Mr. FRANKEL. I was referring to the Department of Energy programs, whether they were covering all the bases or whether there are other large parts missing.

Mr. STINSON. The main cooperative venture now is conversion of agricultural type crops to ethanol. We were working with DOE in fleet testing but we had to get out of that because we really didn't have the facilities to store the various liquids. That is the main area that we are in now.

Mr. HEITOWIT. I'd like to thank this last panel for concluding what I think was a very interesting and stimulating symposium. I want to thank you, gentlemen.

In closing, I'd like to address my remarks to those in the audience who may have come recently and not been here when we started. We had intended to have a real hearing, a congressional hearing here today of the Subcommittee on Energy Development and Applications of the Committee on Science and Technology, one of the standing committees of the U.S. House of Representatives.

The people you see before you up here are actually staff members of that committee, we are not Congressmen. The Congressmen fully intended and looked forward to coming to Knoxville to the World's Fair for this hearing. Unfortunately, as some of you may be aware, the U.S. House of Representatives had a long, protracted and inconclusive debate on the first budget resolution, and was still debating last night at 1 o'clock in the morning. There were a number of very important votes. So none of the Members could get away and come to Knoxville and be present at the hearing.

But our chairman, Chairman Fuqua from Florida, directed the staff to come here and hold the meeting in any case, as a symposium with our distinguished group of scientists and technicians from around the Southeast. We were pleased to do so.

We wanted you all to know that bureaucrats like ourselves from Washington do get out into the real world. We were very pleased to come here; it was very interesting for us, and I think we accomplished important business for the committee.

So thank you all. We want to thank the Department of Commerce, which runs the U.S. Pavillion here, for allowing us to use their Western Plaza. It was, for the most part, rather accomodating. It kept most of us dry most of the time. We would like to thank the crew from the World's Fair for the sound system. We think it performed adequately under the circumstances. Thank you for your attention and for staying with us throughout the whole day.

We want to thank our assistants and guides from the World's Fair and those who volunteered technical assistance.

Thanks to Mrs. Pearson, who came down from Washington, who is making a transcript that will be published. Thanks to you all. Good afternoon. The meeting is adjourned.

[Whereupon, at 4:05 p.m., the subcommittee adjourned.]

# RENEWABLE ENERGY IN THE EIGHTIES: RESEARCH NEEDS FOR SOLAR ELECTRIC TECHNOLOGIES

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WEDNESDAY, JULY 28, 1982

House of Representatives,
Committee on Science and Technology,
Subcommittee on Energy Development and Applications,
*Washington, D.C.*

The subcommittee met, pursuant to notice, at 1:32 p.m., in room 2318, Rayburn House Office Building, Hon. Don Fuqua (chairman of the subcommittee) presiding.

Present: Representatives Fuqua, Wolpe, Nelson, Skeen, Dunn, Gregg, and Weber.

Mr. Fuqua. The subcommittee will be in order.

In April of this year, the Energy Daily published OMB's fiscal guidance to DOE for fiscal years 1984 through 1987. The guidance revealed what many of us had long suspected: By 1985 the Nation's conservation and solar programs will be virtually eliminated.

According to the OMB scenario, in 1985 there will be no funds for conservation research in the DOE budget and only $40 million for all of solar energy, a program that once commanded a budget of $576 million.

It is hard to believe that there is no research in energy efficiency that meets OMB's long-term, high-risk, high-payoff criteria. It is equally hard to believe that among seven solar technologies representing four different renewable resources, only $40 million worth of research is needed to resolve the many scientific, technical, and economic uncertainties that remain.

Clearly, the Department has not made a serious effort to identify and evaluate the research requirements for the renewable energy technologies over the next few years. However, the subcommittee continues to think that these technologies are serious options for the Nation's energy future. Therefore, we have initiated a yearlong study to examine where federally funded R&D is justified for renewable energy systems. We are drawing on the wisdom and experience of researchers, managers, and other officials outside of Congress who have been working on these problems to help us identify those research areas.

Today's hearing is part of that study. We have already had a staff seminar in Knoxville, Tenn., in which we examined, in depth, the research needs for biomass and alcohol fuels. Last week, at our hearing on building energy research, we received an excellent set of proposals for research on passive and active solar systems.

Today we turn our attention to the programs which have historically received the largest share of the DOE solar budget: Photovoltaics and solar thermal power systems. We have with us today the directors of the solar electric programs at two of the principal DOE laboratories, the Jet Propulsion Laboratory and Sandia.

We also have the pleasure of welcoming to the subcommittee for the first time, the new director of the Solar Energy Research Institute, Dr. H. M. Hubbard.

Our second and third panels consist of witnesses from the private sector and the university and research communities who are familiar with the technologies under consideration.

Gentlemen, we would like to welcome you here today. We will first begin with Dr. Hubbard, whom I have mentioned, Dr. Donald Schueler, the manager of the Solar Energy Department of Sandia, and Mickey Alper, the manager of the Solar Energy Program at JPL. If you will take the stand, we shall proceed.

If you have prepared statements, you may submit them. We will make them in their entirety part of the record, and if you wish to briefly summarize your statements, that would be greatly appreciated. We may have some time constraints this afternoon, because of the House being in session and events that will take place later in this room.

At this time I would like to recognize our colleague from New Mexico, Mr. Skeen.

Mr. SKEEN. Thank you, Mr. Chairman.

I am looking forward to today's hearing on research needs for solar electric technologies, and I would like to commend you for focusing the subcommittee's attention on our future renewable energy research needs.

Mr. Chairman, the State of New Mexico has been and will continue to be at the forefront of this country's effort toward making solar electric power widely available at competitive cost. In that regard, I am especially pleased that the Land of Enchantment is so well represented at this hearing.

I would like to welcome Dr. Don Schueler, the manager of the Solar Energy Department at Sandia National Laboratories, who brings us his extensive knowledge and experience in research at one of the pillars of this country's research facilities at Sandia National Laboratories.

Also, finally, Mr. Chairman, I would like to extend greetings to Dr. John Schaefer, who is on the second panel, and who is the director of photovoltaics for the New Mexico Solar Institute at New Mexico State University. As project director of the Southwest Residential Experiment Station, Dr. Schaefer sees the end result of our research efforts, and I look forward to hearing his testimony, his projects, and his thoughts on the national photovoltaics program.

Again, I would like to welcome you both to the committee. I look forward to your testimony.

Thank you, Mr. Chairman.

Mr. FUQUA. Thank you, Mr. Skeen.

Dr. Hubbard, we will be pleased to hear from you, and, welcome to the committee.

## STATEMENTS OF DR. H. M. HUBBARD, DIRECTOR, SOLAR ENERGY RESEARCH INSTITUTE, GOLDEN, COLO.; DR. DONALD SCHUELER, MANAGER, SOLAR ENERGY DEPARTMENT, SANDIA NATIONAL LABORATORIES, ALBUQUERQUE, N. MEX.; AND MICKEY E. ALPER, MANAGER, SOLAR ENERGY PROGRAM, JET PROPULSION LABORATORY, PASADENA, CALIF.

Dr. HUBBARD. Thank you, Mr. Chairman. It is a pleasure to be here before this committee for the first time because the committee, as you all know better than I, was instrumental in the establishment of the Solar Energy Research Institute.

I was asked to review briefly the current status of the Institute and, in addition, to comment on solar electric technologies. The details are in my statement, but I would like to summarize them for you.

Mr. FUQUA. Thank you.

Dr. HUBBARD. As you know, Public Law 93-473, which established the Institute, simply stated that there would be an Institute and it would perform such research, development, and related functions as the chairman may determine necessary or appropriate.

That is not very specific language. It is flexible. In its early stages, the Solar Energy Research Institute was involved in many different activities. It was involved in market-related studies, policy and program planning, management of international solar programs, socioeconomic and environmental studies, public information dissemination, and projects aimed at commercialization, in addition to the R&D function.

There is no denying that a great deal of useful work came out of that period. It is also true, I think, that the constant changes in size and organization and in program direction hindered SERI's ability to focus its performance on scientific research and development.

In early 1981, the management of SERI and MRI concluded that a greater concentration on research and development of solar technologies was appropriate and was consistent with the guidance we were receiving from the Department at that time.

Therefore, in the past year, we have redirected SERI's mission and its activities. The redirection involved changes in program emphasis and in our skill base, and a reduction in staff. Out of this came a redefined SERI which I think is now approaching stability.

We now have a defined mission. Our mission statement, as recently approved by the Department of Energy, states:

> The mission of the Solar Energy Research Institute is to be the Nation's primary Federal laboratory for solar energy research and to perform functions assigned by the Department of Energy in research, development, and testing. SERI carries out its mission by conducting and coordinating long-term, high-risk research and development on solar technologies, which private industry cannot reasonably be expected to undertake. This work advances scientific understanding and establishes a sound technological base, enabling the private sector to make well-informed choices among technology options.

In accordance with that mission statement we have restructured SERI, so that it now has three major research divisions: Solar Thermal and Materials Research, Solar Fuels and Chemicals Research, and Solar Electric Conversion Research.

I would like to make a few comments now on my own convictions before I turn back to the principal topic of today's hearing, and afterward I will comment on the outlook for SERI.

A new acquaintance of mine recently asked me how I got into research management. I got into research management for the simple reason that I am a scientist and a professional research manager. I believe that the solutions to most of the problems of today's society require a strong base in science and technology.

This is particularly true of the energy problem. It certainly requires a strong base in science and technology. I am convinced that to meet our energy needs and to minimize related problems, we must use all our energy resources, particularly renewable energy resources.

The Midwest Research Institute, as the contractor-operator for the Solar Energy Research Institute and its management and Board of Directors, share that view with me. We believe that the redirection of SERI to emphasize long-range research and development will enhance SERI's ability to contribute to the establishment of solar energy as one of the Nation's energy resources.

I think the Institute now has the necessary sense of mission and that it is now achieving the stability and maturity required of an outstanding research and development laboratory. But the successful conduct of long-term research requires stability—stability of staff, stability of resources, and continuity in planning.

On February 24, 1982, before the House Committee on Energy and Commerce, Secretary Edwards stated that it is the administration's long-term view that SERI will be the lead center for solar research in the overall Federal program of long-term, high-risk, high-payoff research.

We welcome and support that statement as another major step toward a stable and effective SERI. I am therefore optimistic about SERI's future, based on the assumption that program continuity at our present level of effort will be sustained through the next 5 years. We have momentum, and we can build on that.

Now I would like to turn to the principal subject of today's hearing, namely, SERI's work in solar electric technologies and solar thermal and photovoltaic research.

Solar thermal research is a major segment of SERI's program, and our program emphasizes solar thermal energy for the generation of electricity. Each solar thermal technology depends on collection and concentration of the Sun's rays onto receivers. In the receiver, a working fluid like water, oil, or gas is heated and then sent to a converter where it is transformed into mechanical, electrical, or chemical energy or used directly in an industrial process, like drying fruit or bleaching cotton.

The work at SERI focuses on areas that cut across all solar thermal technologies. What we are emphasizing is research on components that either reduce the cost of solar thermal electric systems or improve their performance and reliability. In other words, we are seeking to improve both the efficiency and the reliability of solar thermal systems.

Now we are concentrating on solar mirrors as well as doing materials research on absorber coatings, ceramics, and high-temperature salts. We also want to work on innovative receiver concepts and high-temperature storage concepts.

The principal things in solar thermal research that SERI has accomplished recently are evaluation of new thin glasses for solar mirrors, mechanisms that affect silver glass mirror performance and extend its life, and a cermet selective absorber for improved performance in receiver applications.

We are also working on improving polymers, the development and characterization of polymer materials that are important in receivers and collectors, and on new concepts for concentrators.

Our highest priorities in solar thermal research are those things that have direct applicability to solar thermal electric systems. This includes low-cost collector materials based on new polymers, applied research on new concentrator concepts, research on high-temperature materials and fluids for thermal storage and receivers.

Our next priorities are salt-gradient solar ponds and the utilization of concentrated sunlight for fuels and chemicals.

The largest area of research at SERI is photovoltaic research in which SERI is the lead center for advanced research and development for the National Photovoltaics Program. We have responsibility for overall planning and execution of the advanced R&D programs. These include in-house research and program management of a budget of about $15 million in 1982. We have about 85 subcontracts with universities and small and large businesses. Approximately about 42 percent of those contracts are with universities, and about 8 percent with small businesses.

We have two basic approaches to photovoltaic research. One focuses on reducing photovoltaic module costs at some sacrifice in conversion efficiency by developing polycrystalline and amorphous thin-film photovoltaic cells on low-cost substrates. The other is to develop high-efficiency cells, recognizing that they are higher in cost but that, used with mirrors and concentrators and luminescent flat plates, they can be cost effective and can generally improve our ability to make photovoltaics practical.

The Institute has a very sophisticated photovoltaic materials and device measurement capability. With this we are supporting both internal and external research with measurement data that just cannot be obtained anyplace else. The photovoltaics program has made tremendous progress in understanding how to prepare photovoltaic materials, their properties, and cell efficiency. We think that should be continued.

SERI does cooperate with the Technology Development and Applications Lead Center at the Jet Propulsion Laboratory and with Sandia National Laboratories. We see these two laboratories as complementary and supplementary to SERI. It is our intention to work cooperatively and effectively with them, and I think that we do that.

SERI has a large number of photovoltaic accomplishments. Let me just mention the first three on my list and refer you to the others in the handout. There is a novel process for growing sheet silicon using an edge supported pulling technique. There is a new purification technique using electrorefining for producing high-purity silicon from metallurgical grade silicon. There are much-improved thin-film PV cells and a whole collection of other things that relate to improved thin-film technology and a better understanding of photovoltaic phenomena.

What we would do in the long-term development of photovoltaics is to give the first priority to basic and exploratory developmental research on amorphous silicon materials and cells.

The second priority would include research on very high-efficiency cells and on thin-film materials and on measurements and support activities.

The third priority is additional research on the nature of polycrystalline silicon to further understand grain boundaries, and the problems inherent in their structure which limit the efficiency of polycrystalline devices.

Additional priority areas include photovoltaic electrochemical cells, luminescent concentrators, and the development of innovative materials.

We have copies of the Solar Energy Research Institute's Institutional Plan, 1982 to 1987, for members of the committee who would like more complete details on our progress.

With me today is the Deputy Director of SERI, Dr. Donald Feucht, whose particular area of expertise is photovoltaics. We would be glad to reply to any questions that the committee may have.

Thank you, Mr. Chairman.

Mr. FUQUA. Thank you very much, Dr. Hubbard.

We shall continue with the other witnesses on the panel and then ask questions of all three of you at the conclusion.

Dr. Schueler?

Dr. SCHUELER. Mr. Chairman, Congressman Skeen, I also appreciate the opportunity to present my opinions on research needs for solar electric technologies and to discuss the role of the Federal Government in this regard.

I have been involved in solar energy development since the Federal Government renewed its interest in this area back in the mid-1970's.

My current responsibilities at Sandia National Laboratories include management of those parts of the Department of Energy's solar programs for which Sandia has responsibility. This includes engineering and technology development on distributed solar thermal collectors, on photovoltaic systems, and on concentrating photovoltaic collectors and on vertical-axis wind turbines.

I would like to summarize the major points contained in my written statement. Let me begin by stating that at their present state of development and in the current economic environment, I believe that Federal support of solar electric technologies over the next 5 years, at a minimum, is essential to establishing these technologies as a viable choice for the future.

Private investment in solar electric technology is currently quite small, and the associated risks are high. Even with financial incentives available to private industry today, I believe that discontinuance of Federal support for research and development would seriously jeopardize the existence of the current technology.

In my written statement, I have provided a short assessment of the current status of solar thermal and photovoltaic technologies and a list of specific research needs for each technology. I shall be glad to discuss these recommendations further with you or provide more detail later if that is desired.

The major point I would like to make about the nature of federally sponsored R&D for solar electric technology is that I believe it is most effective when a balance between basic research, technology development, and engineering proof of concept is maintained. By the very nature of the technology, all of these activities are long range and high risk in nature, and only by active interaction with hardware development and system level feasibility experiments can basic research remain focused on the most important problems.

Therefore, the list of recommended research activities that I have provided in my written statement spans a range of basic research on materials and processes to engineering and technology development, to system-level feasibility experiments. Indications that I get from private industry indicate that a balanced program such as this is most useful to them, and they should be encouraged to provide participation with their own funds wherever possible, especially in the system-level experiment activities.

A final comment: Although I believe that pursuit of renewable energy resources and especially solar electric technologies is a very sensible and important activity for the Federal Government, I also believe that we must be realistic about our expectations, about energy production from a new and radically different energy technology, and we must develop a steady, properly balanced, and time-phased Federal policy that encourages the progress toward technology that can have national significance.

Thank you.

Mr. FUQUA. Thank you very much, Dr. Schueler.

Mr. Alper?

Dr. ALPER. Mr. Chairman, members of the committee, I thank you for the opportunity to appear before you today. I will try to provide some information and some insights which have been developed over a number of years with the Jet Propulsion Laboratory's involvement in terrestrial energy technology, first for the National Science Foundation [NSF], then for the Energy Research and Development Administration [ERDA], and most recently, of course, for the Department of Energy [DOE].

Our oldest involvement is within the photovoltaic program. We developed systems to provide space power in the 1960's for NASA. In 1972, we supported NSF in helping to identify the present program. We were given the responsibility for the low-cost solar array project. We were also asked to perform the functions of the photovoltaic lead center for technology development and applications. In this role, we provide the DOE with support in planning and assessing the activities and identifying options for them to consider with respect to future funding.

In the solar thermal area, we have been involved in parabolic dish, high temperature solar electric systems, first in studies for space applications for NASA in the 1960's and then finally for ERDA and the Department of Energy, where we have the responsibility for developing parabolic dish technologies using automobile-size engines at the focal point to generate electricity. We were also involved recently in supporting the Department of Energy in examining the applications of salt-gradient solar pond technology in the Salton Sea in California as part of an activity which is jointly funded by the Energy Department, the State of California, and the Southern California Edison Company. We were also requested to assess the applicability of salt pond technology in the United States.

As a result of my involvement with these technologies over the past 10 years, I believe that each has the technical and economic potential to make a significant contribution to the future electricity supply in the United States. Each technology has identifiable market potential where it can make a unique contribution. There are also a number of areas where they overlap. Eventually, the marketplace will ultimately resolve those issues about which technology should be used and where. Until the technologies are developed and those marketplace decisions can be made in an informed fashion, I support the other witnesses in agreeing that a significant amount of R&D still is necessary to be performed.

The research needs I have identified indicate a number of areas in each of the technologies for which we have responsibility. The areas tend to be at the technology base and technology development end of the R&D spectrum. If you consider the spectrum of activities to be a technology base which includes basic research, applied research, and exploratory development, a technology development area which includes systems and subsystems activity and field experiments and finally commercialization activities which include product development, pilot plants, and demonstrations and, finally, commercial use; our interests, of course, tend to be in the applied research and exploratory development areas, with a significant amount of experience in the subsystem, system, and field experiment domain—which I would like to talk to these field activities later.

In our activities, we always try to identify some objectives to provide R&D management guidance to the development of the program supporting the activity. We have always assumed that the objective of the energy programs is to develop a viable technology in a 5-, 10-, or 15-year time frame, which has the potential for eventually making a substantial contribution to the U.S. supply of electricity.

The term "viable" as I have used it means that the technologies have to be able ultimately to be produced, sold and used at an unsubsidized cost which allows them a significant niche in the supply of U.S. electricity. They have to be compatible, in this country at least, with the electric utility system, since the electric utility grid reaches everywhere, and they must be able to be produced and operated in a way which is both environmentally and institutionally acceptable.

The areas of research identified in the written testimony tend to meet one or more of the following characteristics: They either are a high-leverage activity having a significant potential impact ultimately on the cost of delivered electricity or they are a research activity whose results are not easily appropriable by the performer. In this latter case, private sector activity is not likely to be captured in terms of private sector gains, and private sector support of such activities tends to be inhibited. Finally, there are those activities which provide the technical information as well as potential cost information necessary to reduce uncertainties in application, since the reduction of uncertainty is probably one of the more significant results a Federal program can produce in order to encourage private sector investment and involvement.

In the photovoltaics area, I have identified a number of activities associated with silicon. Here, of course, we mean either single-crystal silicon or polycrystalline silicon which can be produced in the forms of webs or other forms of drawn thin sheet. I believe that the Federal program to date has brought a number of these silicon technologies to within a factor perhaps of four where they need to be commercially attractive in a grid-connected market, although the present selling prices are still probably a factor of ten away. A number of technology base and technology development areas worthy of continued work remain. Some of the materials research which the Solar Energy Research Institute (SERI) has been performing is maturing and is ready to be given some of the same kinds of engineering development and applied engineering activities that the silicon materials have received over the last 4 or 5 years. You have already received some recommendations and comments from both SERI and Sandia with respect to research activities, concentrating collectors, and balance of system work. All of this activity, in a balanced program, collectively constitutes the research needs for this technology in the next 5 years.

In the parabolic dish technology, the program has defined a set of first and second generation goals which, when reached, will permit the technology to either be used in midterm markets or eventually to be competitive with more conventional means of generating electricity. The program has relied heavily on engine developments made in the DOE automobile program for advanced engine technologies. Primary needs in the next 5 years are some specific subsystem improvements and the establishment of an effective field system test.

Salt-gradient pond technology can be used, as you probably are already aware, to either generate thermal energy or electricity. I speak specifically to the electricity-generating pond potential, which tends to imply fairly large ponds. Experience in this area exists primarily in Israel, where R&D has been carried on over the past 15 or 20 years, and in a number of the national laboratories and universities which have performed research on small ponds in the last 5 or 6 years in this country.

The planned Israeli activities include the development of a 60-acre pond in the Dead Sea. I believe the American program should consider both a technology-based R&D activity as well as an American version of the Israeli system field experiment. I think this is worthwhile for two reasons: First, we have learned in our work to date that a number of salt pond problems tend to be site-specific, and the identification of methodologies and approaches to be able to handle these site-specific problems needs to be identified.

Second, by involving the Israeli contractors in a work such as this, a significant amount of their experience can be obtained in this country in a relatively short time.

I would like to briefly dwell on one area of technology development which I think is important. I mentioned before the technology base, technology development and commercial development activities. I think it is useful to consider the technology development as a technology "bridge" between the base activities and industry's commercial involvement. In addition to being a bridge, I think this area of work is also important in its own right. It is particularly important in its own right because in this area you find system activities and system field tests. Technology development generally provides the only focus for system-related technology development and system-related problem identification. Field experiments in this area are very often expensive to perform and, therefore, can only occasionally be completely supported by the private sector.

I believe a distinction needs to be made between system field experiments and demonstrations. The field experiments have to be particularly well planned with respect to size and site, and they need to be modular and flexible so they can provide for both the research community's needs as well as the private sector's needs. They need to be performed according to a test and operations plan which evaluates the needs of the researchers for information before the system is built. Instrumentation required must be developed to permit the information to be obtained, and I also believe that analytical predictions of performance should be obtained so one can compare the predictions with the actual test results in order to better assure that one's areas of understanding are in fact known. Information dissemination needs to be planned at the beginning of these field tests to make sure that both the private sector needs as well as the research needs are satisfied.

Finally, I believe that any of these activities require effective, coordinated, multiyear planning with adequate consideration given not only to the research base but also to the industry needs for information. In that vein, it is important to recognize that the industry interested in solar electric technology is broad and very diverse, and one has to disaggregate an understanding of their needs in order to effectively plan for the spectrum of people who have concerns. I further believe that these activities should be goal oriented and have to be focused ultimately on the ability of the technology to deliver a cost-effective product—that is, electricity—to the country.

Finally, to do this kind of planning in an effective way takes a cooperative effort amongst the laboratories which I believe has been well developed over the last several years, and it requires the management and resource availability to do the work which permits this planning.

Thank you.

[The prepared statements of Dr. Hubbard, Dr. Schueler, and Mr. Alper follow:]

# TESTIMONY OF DR. H. M. HUBBARD
DIRECTOR
SOLAR ENERGY RESEARCH INSTITUTE

BEFORE THE
U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE AND TECHNOLOGY
ENERGY DEVELOPMENT AND APPLICATIONS SUBCOMMITTEE
RENEWABLE ENERGY IN THE EIGHTIES: RESEARCH NEEDS
FOR SOLAR ELECTRIC TECHNOLOGIES

Washington, D.C. July 28, 1982

Good Morning, Mr. Chairman and members of the Subcommittee. My name is H. M. Hubbard, and I am the Director of the Solar Energy Research Institute. It is a welcome opportunity to be here today to provide information about SERI and its role in the federally sponsored research and development of solar electric technologies over the next five years.

## THE SOLAR ENERGY RESEARCH INSTITUTE

As you know, SERI was established by an Act of Congress in 1974 to enhance the contribution of solar energy to our national energy resources. Here is the actual wording from Public Law 93-473, October 26, 1974:

> SEC. 10. (a) There is established a Solar Energy Research Institute, which shall perform such research, development, and related functions as the Chairman may determine to be necessary or appropriate in connection with the Project's activities under this Act or to be otherwise in furtherance of the purpose and objectives of this Act.

This wording was flexible and gave sufficient latitude to the Department of Energy in its directions to SERI that in its first years of operation the Institute performed work in many areas other than the focused research and development work now emphasized. SERI was thus involved in many market-related and other studies, including policy and program planning, management of international solar programs, socioeconomic and environmental studies, public information dissemination, and projects to accelerate the commercialization of solar technologies — in addition to its R&D program and contract management responsibilities.

Much useful work came out of this period of diversified activities but the constant change in size, organization, and programs that took place during the Institute's early years hindered SERI s ability to focus its performance on what we now perceive as the fundamental mission: scientific research and development.

### SERI's Mission

Consistent with guidance received from the Department of Energy in early 1981, SERI and Midwest Research Institute (MRI), operator of SERI, concluded that greater concentration on research and development of solar technologies was appropriate; high-priority areas were to be strengthened, and activities not consistent with SERI's new focus were to be reassigned to other institutions, or terminated if the Department of Energy chose.

Accordingly, during the past year, SERI has undertaken and accomplished a major redirection of its mission and activities. This redirection has resulted in a more focused effort in the program areas we believe have the highest potential and represent the best investment of the public funds available for renewable-energy research and development. SERI's present role is to conduct high-risk, potentially high-payoff research and development of solar energy resources in order to advance scientific understanding and establish a technological base so that private enterprise may select energy production options for demonstration and commercialization in the marketplace. This redirection involved changes in program emphasis and reduction of staff, as well as a change in the skill mix of the remaining staff. Finally, SERI has strengthened its institutional management structure to ensure effective use of available resources.

Following is a statement of SERI's mission as recently approved by the Department of Energy:

> The mission of the Solar Energy Research Institute is to be the Nation's primary federal laboratory for solar energy research and to perform functions assigned by the Department of Energy in research, development, and testing. SERI carries out its mission by conducting and coordinating long-term, high-risk research and development on solar technologies, which private industry cannot reasonably be expected to undertake. This work advances scientific understanding and establishes a sound technological base, enabling the private sector to make well-informed choices among technology options.

### SERI Research Areas

SERI has been restructured in three research divisions to implement its new mission. These divisions are described below:

**Solar Thermal and Materials Research** activities include research on active, passive, and hybrid heating and cooling systems; solar thermal research, primarily for advanced technologies for the industrial and utility sections; thermal energy storage; and ocean energy conversion. Materials research at SERI identifies, develops, and evaluates promising materials for all the solar thermal technologies. These include materials for absorbing, transmitting, and reflecting solar radiation; materials for advanced structural support; and working fluids. As in other SERI programs, this work addresses research and development that most private companies cannot support.

**Solar Fuels and Chemicals Research** is concerned with the development of efficient photoconversion processes for the production of fuels and chemicals from sunlight. Technologies studied include photochemistry, photoelectrochemistry, photobiology, biotechnology, and thermochemistry. Applications include the production of hydrogen, ethanol, and methanol, and the thermochemical storage of energy.

**Solar Electric Conversion Research** involves the conversion of sunlight into electricity through the development of photovoltaics (PV) and innovative wind concepts. SERI will continue its lead mission in photovoltaics advanced R&D, which comprises the identification of promising new PV materials and the development of advanced devices for the direct conversion of solar energy, plus further understanding of basic PV phenomena and measurement of material properties.

I will return to solar electric conversion and SERI's electric-power-related solar thermal research after I have touched on some personal convictions.

### The Outlook for SERI

With your permission I would like to give the Subcommittee some insight into my personal perspectives on science and technology in relation to solar energy.

A new acquaintance recently asked me, "How did you get into research?" It was one of those simple questions that catch one off guard because the answers are usually taken for granted. I got into research because I am a scientist and because I am convinced that the solutions to many of our nation's problems, including the energy problem, require a strong base in science and technology. I am also convinced that to meet our energy needs and to minimize related problems we must use all our energy resources — particularly renewable energy.

The Board of Directors of MRI, as well as the management of both SERI and MRI, share these views. We believe that the redirection of SERI to emphasize and increase its research and development role will enhance SERI's abilities to contribute to the goal of establishing solar energy as one of the nation's energy resources. The Institute has the necessary sense of mission and is now achieving the stability and maturity required of an outstanding research and development laboratory. The successful conduct of long-term research requires stability of staff and resources as well as continuity in programming.

On February 24, 1982, before the House Committee on Energy and Commerce, Secretary Edwards of DOE stated:

> It is the Administration's long-term view that SERI will be the lead center for solar research in the overall federal program of long-term, high-risk, high-payoff research and development.

We welcome and fully support the Secretary's statement as another major step toward a stable, effective SERI. I am optimistic about SERI's future, based on the assumption that program continuity and our present level of effort will be sustained through the next five years. In that environment, we can build on our present momentum.

Now let me turn to the specific subject of today's hearing and discuss SERI's work in photovoltaics and solar thermal research.

## SOLAR THERMAL RESEARCH

A major part of the Solar Thermal R&D Program is the application of solar thermal energy for the generation of electricity. Each solar thermal technology, with the exception of solar ponds, depends on the collection and concentration of the sun's rays onto receivers. In the receiver a working fluid such as water, oil, or gas is heated to deliver thermal energy directly to a process or to be converted into mechanical, electrical, or chemical energy. Research at SERI focuses on areas that cut across all the solar thermal technologies. Emphasis is on components that either reduce the cost of a system or improve its performance and reliability.

Since solar mirrors account for approximately 40 percent of a system's initial capital cost, most of SERI's solar thermal research is aimed at reducing the cost of these mirrors. This includes materials research on polymers and thin-glass mirrors to develop long-lived, lightweight concentrators, and research on innovative concentrator concepts. The principle of stretched membranes for rigid lightweight structures is currently being investigated.

Several research activities are aimed at improving the performance and reliability of solar thermal systems. Materials research on absorber coatings, ceramics, and high-temperature salts is being conducted to increase the operating temperature range and thus the efficiency of solar thermal systems, and to enhance systems reliability. High-temperature receiver concepts which collect the highest possible percentage of the concentrated solar flux and efficiently transfer the heat energy to the working fluid are being explored to improve the system efficiency. High-temperature storage concepts which extend the operating duration of solar thermal systems and allow uninterrupted system operation during short cloudy periods are also being investigated. Reliable storage systems for the entire operating range of solar thermal systems are important for large-scale solar electric operations.

**Major Solar Thermal Research Accomplishments**

- o The experimental evaluation of thin glass for solar mirrors has been completed and found suitable for use in next generation mirrors.
- o Mechanisms that effect silver glass mirror performance in the solar environment have been identified.
- o A cermet selective absorber coating for improved performance and lifetime has been developed.
- o Techniques for measuring changes in polymer performance and characterizing polymer materials in the laboratory under accelerated conditions has been developed. This technique will be verified through comparison with performance under the natural solar environment.
- o New concepts for concentrators using lightweight membranes for reflectors have been tested and shown to have good potential.

**Future Solar Thermal Research Priorities**

SERI's highest priority solar thermal advanced research areas are those that have direct applicability to the use of solar thermal electric systems. These include research on polymer materials for low-cost collectors, applied research on innovative concentrator concepts, and research on high-temperature materials and fluids for thermal storage and receivers. Next priority is given to various studies on salt-gradient solar ponds and on the utilization of concentrated sunlight for fuels and chemical processes.

## PHOTOVOLTAICS (PV) RESEARCH

SERI is the lead center for Advanced Research and Development (AR&D) for the National Photovoltaics Program. The goal of this program is to establish the technology base and demonstrate technical feasibility for various advanced material technologies through a strong research and development program. SERI has responsibility for overall planning and execution of these activities, which include conduct of inhouse research and program management of externally contracted research with an FY 82 budget of $15M. More than half of the research funds are used for approximately 85 subcontracts with universities, small and large businesses, and other national laboratories. Approximately 42% of the subcontracts are with universities and 8% with small businesses.

Two approaches are being pursued in order to achieve the technology goals of the program. One approach is to focus on reducing PV module cost at some sacrifice in conversion efficiency by developing polycrystalline and amorphous thin-film photovoltaic cells on low-cost substrates. The other is to develop higher efficiency cells, which may be of higher cost, to use with low-cost mirrors, lenses, or luminescent flat plates which concentrate the solar radiation on the cells. If high-efficiency multiple bandgap cells are used with mirrors or lenses, conversion efficiencies greater than 30% appear attainable. Within each area, several material and processing approaches are being investigated. In addition, the Institute has a strong photovoltaic materials and device measurement capability which supports internal and external research with data not otherwise available.

The advanced photovoltaic materials area is rich in approaches and ideas and one in which tremendous progress in materials understanding, preparation, and cell efficiency has been made during SERI's lead responsibility. During this time, four materials have been approximately doubled in efficiency so that they all exceed or closely approach 10%; other materials once considered promising have been dropped from the program. We believe that the great potential of low-cost thin-film cells and high-efficiency cells can be achieved with a strong AR&D program.

SERI cooperates with the Technology Development and Applications Lead Center at the Jet Propulsion Laboratory (JPL) and with Sandia National Laboratories in carrying out the overall photovoltaics program for the Department of Energy. These two organizations conduct technology and engineering development in those approaches that have achieved technical feasibility, and conduct application and system experiments to provide the necessary experience and feedback for the research program. In addition, SERI and JPL provide planning support for the Department of Energy.

### Major PV Research Accomplishments

o A novel process for growing sheet silicon using the "Edge Supported Pulling" (ESP) technique has been invented by Dr. T. Ciszek of SERI. Using ESP, silicon sheet can be pulled at rates 5 to 10 times those of dendritic web or edge-defined film-fed growth (two processes presently being commercialized by industry). Intrinsic to ESP is edge stabilization, which minimizes temperature and process controls and thus should yield lower cost silicon sheet.

o A significant purification technique, using electrorefining for producing high-purity silicon from metallurgical silicon in one step, has been developed in our laboratories. The technique, invented at SERI by Dr. J. Olson, involves the electrochemical transport of silicon from an anode of a mixture of copper and silicon to a graphite cathode. Silicon transport out of the anode is significantly more rapid than impurity transport so that the silicon deposited on the cathode is 99.9995% pure. Rough estimates indicate as much as a 10-fold cost reduction.

- The first truly thin-film cells to reach 10% efficiency have been fabricated under subcontract to SERI. These (CdZn)S/$CuInSe_2$ thin-film (5-μm thick) cells appear inherently stable and have a conversion efficiency of approximately 10% as compared with 5-6% only two years ago.
- A unique photovoltaic laboratory has been developed at SERI for the evaluation and characterization of advanced photovoltaic materials and devices prepared by SERI, universities, and industrial R&D laboratories throughout the nation. In addition to serving as a national measurement resource dedicated to photovoltaics, the laboratory has provided facilities for the development of new measurement techniques for photovoltaics and the semiconductor industry.
- The federal AR&D thin-film amorphous program has led to significant industrial involvement and cell efficiencies of 8% or greater. It is important to the U.S. that we continue a strong program in both research and process development. The Japanese are also very active in these areas and are not only near the forefront in cell research but are clearly the leaders in process development and manufacture of amorphous silicon cells for consumer items (watches, calculators, etc.).
- Photoelectrochemical cells, which can both generate and store electrical energy depending upon their mode of operation, have demonstrated efficiencies as high as 14% and stabilities of several months as compared to a period of days just a couple of years ago. These cells are being developed at SERI, with subcontractors, and in other laboratories throughout the world.
- Under subcontract, a thin-film (less than 5-μm thick) single-crystal gallium arsenide cell has been developed using a cleavage process to remove the film from a reusable substrate. A small-area cell produced from this potentially low-cost process has an efficiency of 17%. This technique should also be applicable to the production of high-efficiency multiple bandgap cells.
- A metal interconnected multiple bandgap cell, fabricated through a subcontractor, has an efficiency of approximately 22% at a concentration of 12 suns.

### Future PV Research Priorities

It is important for the long-term development of photovoltaics that we maintain and strengthen the photovoltaics advanced research and development activities. Within the AR&D budget allocated to SERI, the first priority is further basic and applied research on amorphous silicon material and cells. The second level of priority includes research on very high efficiency cells, II-VI and other thin-film materials and cells, and on measurements and support activities. The third priority is further research on polycrystalline silicon to improve the understanding of grain boundaries and to increase the efficiency of crystalline silicon cells. Other priority activities include research on photovoltaic electrochemical cells, luminescent concentrators, and innovative materials and concepts.

## SUMMARY

Copies of SERI's "Institutional Plan: FY 1982 - FY 1987" are available for those Subcommittee members who would like complete details of our research efforts.

Thank you for this opportunity, Mr. Chairman and members of the Subcommittee. I hope my testimony has been of help. Dr. Donald Feucht, Deputy Director of SERI is here with me and we will be pleased to answer any questions you may have.

# TESTIMONY ON SOLAR ELECTRIC RESEARCH NEEDS

to the House Subcommittee on
Energy Development and Applications
July 28, 1982

D. G. Schueler
Sandia National Laboratories
Albuquerque, New Mexico 87185

Congressman Fuqua and fellow Representatives, I appreciate the opportunity to present my opinions on research needs and the appropriate federal role in solar electric technologies. My comments are based on my individual perceptions, having been involved in management of solar projects during the past eight years, and do not necessarily reflect the position of Sandia National Laboratories or of the Department of Energy.

In this statement I will discuss the federal role in solar energy development, review the status of solar thermal and photovoltaic technologies, present my views on technology-specific needs for federally-sponsored research and development over the next five years, and conclude with opinions regarding the possible consequence of alternative federal policies on solar electric technologies.

## THE FEDERAL ROLE

The proper role of government in encouraging the development of renewable energy technologies is a complex and philosophically-based issue. In this statement I shall only address a range of possible government objectives and policies and identify, in my opinion, the most significant. Federal government's objectives in pursuing renewable energy sources can logically include issues of national security, environmental protection, resource preservation, business opportunity, and export development. The latter two issues are more aligned with objectives of private industry, i.e., rate of return on investments, and are more likely to be pursued by such organizations. The issues of national security, environmental protection, and resource preservation are not always in line with industry's narrower objectives. Therefore, in my opinion, the most important government objectives should be the development of an understanding of the relative merits of the various renewable energy technologies in the event of unexpected difficulty in conventional energy supply. Through federally-sponsored RD&D programs, we should be carefully developing insight into the risk, the cost, and the timeframe associated with bringing each potential new technology on line. In this manner, strategic energy options can be better understood and federal policies regarding energy development priorities can be better founded.

Government policy to encourage the development of renewable energy technologies can range from information dissemination, to financial incentives, to active support of RD&D programs. A balanced and properly phased combination of these elements, in my view, is the most effective.

With regard to federally-sponsored R&D efforts on solar electric technologies, I believe they will be most effective if a balance between basic research, technology development, and engineering proof-of-concept is maintained. Basic research can remain focused on relevant problems only through active interaction with hardware development and system-level feasibility experiments.

## CURRENT TECHNOLOGY STATUS

### Solar Thermal

Parabolic troughs represent the most mature of the solar thermal technologies. Practically all private sales and, therefore, substantial utilization of available financial incentives have been represented by this technology. Approximately 24 firms are currently involved in some aspect of trough production ranging from component manufacture to sales of turnkey collector systems. Recent estimates indicate more than one million square feet of collector aperture have been installed over the past several years. Direct federal funding of experimental projects is responsible for roughly one-half this total. Although a great deal of progress in the performance, durability, and cost of troughs has been made as a result of federal support, many manufacturers indicate that some continuing support of trough technology development would be of great benefit. Manufacturers lack the resources necessary to develop advanced materials, components and collector subsystems and perform the environmental testing needed to determine the long-term durability of their products. An extensive trough evaluation capability has been developed by DOE and has been used extensively by the industry. If support for this capability were discontinued, it would probably not be duplicated with private funds.

Central receiver technology has progressed to the point of initial operation of a 10 MWe pilot plant in Barstow, California. A number of advanced receiver concepts have been evaluated in the 5 $MW_t$ central receiver test facility in Albuquerque, New Mexico. Although there has been little private funding of technology development and no private sales to date, there are signs that a number of opportunities are emerging. For example, a 1 MW thermal production unit is being considered for an enhanced oil recovery project and a number of firms have responded to a program opportunity notice from the Southern California Edison Company to provide electrical power from a 100 $MW_e$ central receiver plant. A continuing federal role in the development of advanced concepts and components is still essential to technology progress, however. System studies and experimental results indicate that a receiver/storage technology using molten salt as the working fluid could operate at increased efficiency and with lower installed cost. Preliminary plans have been developed to test this system configuration in the 5 $MW_t$ test facility.

A recently dedicated parabolic dish experiment at Shenandoah, Georgia, represents the major dish installation in the United States although several modules of one to four dishes have been operated at various sites. The major technology efforts currently under way are to develop low-cost dish reflectors and high efficiency advanced heat engines, using the Stirling or Brayton cycle, that can be located at the focal point of an individual dish. As with central receivers, no private sales of dish-electric systems have yet been made, but a number of firms are involved in developmental efforts have indicated interest in commercialization as opportunities develop.

## Photovoltaics

Commercial sales of photovoltaics for remote and specialty applications continue to grow, and it is estimated that in excess of 30 companies are involved in the manufacture or development of photovoltaic cells and collector modules. It is obvious that a substantial industry that can exist without government support is emerging to serve the current commercial market for photovoltaics. As the price of installed systems declines, it is expected that an even larger market for such applications as remote villages and agricultural applications will develop.

However, for photovoltaics to be useful for generation of electricity for conventional applications within the United States, significant reduction in system cost must still be realized. This implies the development of advanced materials and cell fabrication processes as well as low-cost balance-of-system components. Because of the above mentioned market opportunities, industry is not likely to devote significant R&D funds to these high-risk activities. Therefore, federal involvement in the development of these advanced technologies is crucial to continued progress toward viable domestic applications for photovoltaics. Through federal funding to date, substantial progress has been made in both flat plate and concentrating photovoltaic technology. A number of system experiments ranging from small residential to commercial applications of several hundred kilowatts are currently being operated and evaluated as part of the DOE photovoltaics program. These experiments are providing valuable data on system performance and durability.

## RESEARCH NEEDS

At their present state of development, I believe that continued balanced support of basic research, technology development, and system feasibility experiments over the next five years is essential to the vitality of solar electric technologies and their availability as a future energy option.

### Solar Thermal

There are several technology independent areas of research and development which could produce significant benefits for all the solar thermal technologies. These include:

I. Materials

- o Optical Materials - more efficient and durable low-cost reflectors; low reflectance, high temperature enclosures for receivers
- o Thermal Materials - heat transfer fluids and solar absorbers capable of higher temperature operation
- o Structural Materials - low-cost tracking and reflector structures for heliostats and dishes

II. Thermal Science

- o Thermodynamics - advanced high efficiency heat engines
- o Heat Transfer & Hydraulics - advanced receivers, heat exchangers and thermal storage systems

III. Chemistry

- Chemicals - collector and engine working substances and energy storage; thermochemical and photochemical reactions
- Fuels - production of hydrogen and other high quality fuels from solar energy

IV. Engineering

- Advanced Concepts - analysis of new system concepts and technology improvements through performance modelling and design trade-offs
- Hardware Evaluation - performance and durability evaluation of advanced components, subsystems, and pilot-scale systems to validate technical feasibility

The specific areas of research and development as they apply to individual technologies are as indicated below.

I. Parabolic Troughs

- Collector Development - evacuated receivers, durable glass-metal laminate reflectors, high volume assembly processes, and extended durability testing
- Cogeneration System Development - high efficiency extraction turbine, advanced thermal storage

II. Central Receivers

- Advanced Receivers & Storage - molten salts, liquid metals, and high-temperature gases; thermochemical and photochemical processes
- Heliostats - reliable glass mirror modules; advanced lightweight reflectors
- Experiments - verification experiments with advanced receivers and processes using the 5 $MW_t$ test facility and the Barstow pilot facility

III. Parabolic Dishes

- Advanced Collectors -lightweight structures and durable glass mirror modules; higher temperature receiver technology
- Conversion Processes - small focal-point mounted engines of Brayton, Stirling and Rankine cycle type
- Experiments - evaluation of advanced dishes, focal-mounted engines, and power generation equipment

Photovoltaics

Photovoltaic collector costs are the primary obstacle to widespread utilization. If these were sufficiently low, photovoltaics would clearly represent a very attractive electric power generation technology. There are three photovoltaic collector technologies which should be pursued vigorously:

- Flat plate collectors using large area crystalline silicon sheet technology
- Concentrating collectors using Fresnel lenses
- Flat plate collectors using thin film amorphous silicon

In addition, there are two other areas where research support is needed in photovoltaics:

- Subsystem technology development - significant advances are likely in the areas of low-cost modular array field technology, and power conditioning and control subsystems.
- Field testing of experimental systems - this is essential to substantiate development progress.

## SUMMARY

Based on my assessment of the current status of solar electric technologies and their research needs, and on interactions with the solar industry, I believe that Federal Government policies regarding renewable energy research and development during the next decade will be crucial to establishing these technologies as viable choices for the future. Specifically:

- Well-designed positive federal policies toward solar electric technologies, mainly through support of research, technology development, and pilot scale experiments, are required to assure timely development of useful technology. Conversely, poorly-designed policies can be ineffective or delay market development through over-selling technology potential, premature demonstration, or premature financial incentives.

- Private investment in solar electric technologies is currently small and only large firms are able to take the associated high risks. Discontinuance of federal support of research and technology development would discourage further private investment and jeopardize the existence of the current fledgling industry.

- Even with federal support, significant results in terms of energy production should not be expected to occur quickly because thorough R&D takes time, market acceptance takes time, the required investments are large, and integrating sales to significant energy production capacity takes time. Realistically, many decades may be required to bring an emerging renewable energy technology to a point of energy significance on a national scale.

Statement before the Energy Development and Applications Subcommittee
of the Committee on Science and Technology
U.S. House of Representatives
by
Dr. M. E. Alper, Solar Energy Program Manager
Jet Propulsion Laboratory
California Institute of Technology
July 28, 1982

Mr. Chairman, and Members of the Subcommittee,

Thank you for the opportunity to appear before you today. I will provide information and some insights which I hope will be helpful to you in considering the question of research needs for solar electric technologies over the next five years. My comments are based on activities with which I have been associated at the Jet Propulsion Laboratory since the early 1970s: first for NASA and then for the National Science Foundation, the Energy Research and Development Administration and the Department of Energy.

Our oldest involvement is with the photovoltaics (PV) program. After developing and using P.V. power systems for lunar and planetary spacecraft during the 1960's, we performed studies on the development of P.V. for terrestrial use for the National Science Foundation in 1972. They were followed by a program planning activity which led to the Low Cost Solar Array Project which was initiated in 1975. In 1977 we were asked to establish the Photovoltaic Lead Center for Technology Development and Applications. The Lead Center supports the DOE Photovoltaics Energy Technology Division in planning and assessing the activities of the program and in providing options for DOE to consider with respect to future activities.

We performed R&D for space applications of parabolic dish solar thermal power systems for NASA in the 1960's. In 1974 and 1975 we performed studies comparing space power systems to terrestrial solar system alternatives for NASA.

These studies led to our involvement with ERDA in 1977 in the parabolic dish technology program. In addition to the dish technology activities, the Department of Energy asked us to evaluate the application of salt gradient solar pond technology in the Salton Sea in California as part of a jointly funded activity between DOE, the California Energy Commission and the Southern California Edison Company. DOE also requested that we assess the applicability of salt pond technology in the United States.

We are also involved in communication and control R&D for the Electric Energy Systems Division of the Department of Energy. An area of concern is the impact of additional communication and control requirements which could result from adding a large number of distributed electricity generators such as cogeneration systems, fuel cells, photovoltaics or solar thermal dish systems to the utility transmission and distribution system.

As a result of my involvement with the photovoltaic, solar thermal parabolic dish, and electricity producing salt gradient solar pond programs, I believe that each has the technical and economic potential to make a significant contribution to the future electricity supply of the United States. Each technology has identifiable market potential where it can make a unique contribution. There also are areas where they overlap. The marketplace will ultimately resolve the question of which technology best serves which market. There are public values in having these technology options available or commercialized sooner than they might be if all R&D activity was left to the private sector. You are well aware of these values. However, since my view of these public values affects my opinions of R&D needs, let me state them briefly for you. They include:

1. Strengthening the position of U.S. companies vis-a-vis foreign competitors who are usually part of a foreign private/public sector co-operative effort.

2. The early establishment of an industrial base which would permit a diversification of U.S. energy sources needed for electricity generation. A near-term financial payoff is the value of oil displaced by earlier commercialization.

3. The contribution to the alleviation of the U.S. balance of payments problem.

4. The alleviation of environmental problems by substituting more benign sources of energy for electricity production.

5. Permitting the U.S. to support third world and developing countries with energy technology in support of foreign policy initiatives.

## I. RESEARCH NEEDS FOR SOLAR ELECTRIC TECHNOLOGIES

I will identify research needs for solar electric technologies in areas for which the Jet Propulsion Laboratory has had a specific responsibility, i.e. flat-plate photovoltaics, parabolic dish solar thermal, and large salt gradient solar ponds. The activities identified in each technology are in the Technology Base and Technology Development areas of the R&D spectrum. Figure 1. I will then discuss an aspect of the Technology Development portion of the R&D spectrum which I consider to be important. Finally, I will discuss some factors associated with R&D Implementation with which I am sure you are familiar, but which I believe to be worthy of reiteration.

In addition to confining identification of R&D needs to the specific areas mentioned above, I have also assumed that the objective of programs with Federal involvement is to have viable technologies in the next five to ten years which have the potential for eventually making a substantial contribution to the U.S. supply of electricity. By viable I mean that the technologies can be produced, sold, and used at a cost which allows them a significant niche in the general U.S. supply of electricity; that they are compatible with the electric utility system, and that they can be produced and operated in a way which is environmentally and institutionally acceptable.

In preparing the information I have tried to identify areas of research which meet one or more of the following characteristics:

- High-leverage activity having a significant potential impact on cost of delivered electricity.

| Technology Base | Technology Development | Commercialization |
|---|---|---|
| Basic Research | Systems | Product Development |
| Applied Research | Subsystems | Pilot Plants and Demonstrations |
| Exploratory Development | Field Experiments | Commercial Use |

Figure 1. R&D Spectrum of Activities

- Research activity whose results are not easily appropriable by the performer.
- Activities whose results provide technical information necessary to reduce uncertainties associated with the application of these technologies.

## Ia. PHOTOVOLTAICS

The research needs identified here are confined to the flat-plate solar array project. The project began in 1975 and is concerned with both the technology base and technology development activities required to produce flat-plate modules and the systems needed to manufacture them at low cost. The emphasis in the program to date has been on silicon material, either single crystal or polycrystalline. This material has a large research background, is of proven feasibility, and therefore is amenable to technology development.

The cost targets in the program are to have module and process technology available which will permit industry a significant probability of meeting or exceeding the 70¢ per peak watt (1980 dollars) targets which have been established. Although the commercial prices today are still a factor of ten away, a substantial amount of Federally funded effort, predominantly carried out by industry, has brought the silicon technologies to within a factor of four of the program technology readiness targets; however, a number of technology base and technology development areas worthy of continued work remain. In addition, some of the material research at the Solar Energy Research Institute is maturing and is ready to be treated in the same manner in which silicon has been treated over the last five years at JPL. The recommendations for R&D activity are divided into two major areas: flat-plate photovoltaic components R&D, and flat-plate photovoltaic engineering sciences R&D, and are shown in Figures 2 and 3. I am sure that you will receive recommendations from other laboratories involved in the program for research activities, concentrating collectors, and balance-of-system work. All of this activity is important and collectively constitutes the research needs for photovoltaics in the next five years.

**Flat-Plate Photovoltaic Components Research and Development**

- Silicon (Single and Polycrystalline)
  - Silicon Material
    - Fluidized Bed Reactor
    - Free Space Reactor
    - Feasibility Test with Low-Cost Silane "Front-End"
  - Silicon Sheet
    - High-Speed Growth
    - Thermal Stress
    - Material Quality
    - Feasibility of Simultaneous Achievement
  - Environmental Isolation
    - Stable Polymeric Encapsulants
    - Bonding Mechanisms (Coupling Agents, Primers, and Adhesives)
    - Surface Treatments
    - Degradation Mechanisms
  - Processes
    - Junction Formation
    - Metallization
    - Module Formation
    - Effluent Treatment
    - Process Element Interaction
    - Cell/Module Efficiency Limits
- Thin Film
    - Initiate Efforts on Materials, Devices, Environmental Isolation and Process Innovation for Thin-Film Material, Emerging from Research

Figure 2. Flat-Plate Photovoltaic Components Research and Development Needs

- Areas
    - Requirements
    - Array Concepts
    - Electrical Circuit and Safety
    - Durability
    - Module Design Synthesis
    - Performance Testing and Failure Analysis
- Silicon Cell Emphasis
    - Durability
        - Long-Term Temperature/Humidity Effects
        - Ion Migration of Cell Metallization
        - Dielectric Breakdown
        - Interconnect Fatigue
    - Environmental Characterization
        - Safety
        - Performance Testing and Failure Analysis
- Thin-Film Emphasis
    - Cell-Circuit Reliability Optimization
    - Mechanical Fatigue
    - Hot-Spot Heating
    - Cell/Encapsulant Durability
    - Measurement/Testing Infrastructure
        - Electrical Performance Measurement Standard
        - Durability/Qualification Test Methods
    - Design Specifications

Figure 3. Flat-Plate Photovoltaic Engineering-Sciences Research and Development Needs

## Ib. SOLAR THERMAL PARABOLIC DISH TECHNOLOGY

The Parabolic Dish Technology activity began in 1976. The program has been defined to achieve an early or "first generation" set of goals which would make delivered electricity attractive in remote or specific existing markets which have relatively high electricity costs. A "second generation" technology goal has been established which, when met, will result in parabolic dish technology able to produce electricity at a cost which permits the technology to be much more broadly competitive.

The program has relied on technical developments in engines made in the Department of Energy's automotive program for the advanced engine technologies, and has adapted organic Rankine turbine technology for solar use. Modules using organic Rankine, Stirling, and Brayton engines are presently scheduled for initial field tests within the next year. R&D needs for the next five years are identified in the technology development area where system feasibility field tests are needed, and for technology base and technology development in the major subsystems: concentrators, power conversion units, and controls. Specific areas are identified in Figure 4.

## Ic. SOLAR THERMAL SALT GRADIENT POND TECHNOLOGY

Solar Salt Gradient Pond activity began at JPL in 1979. The technology can be used to provide thermal energy or electricity. Electricity generating ponds are generally large while thermal generating ponds can be used in both large and small applications. My comments are restricted to the technologies associated with large ponds for industrial process heat and electricity generation.

Experience in solar salt ponds exists primarily in Israel, where R&D has been carried on over the past fifteen years, and in a number of small ponds in the United States where research has been performed by universities and national laboratories. The planned Israeli activities include the development of 5MW, 62 acre salt gradient pond in the the Dead Sea.

**Complete Feasibility Tests and Evaluate First Generation Technology - Organic Rankine, Stirling, Brayton**

**Conduct System Feasibility Field Tests**

**Develop Advanced Parabolic Dish Systems**

- **Concentrators**
    - **Low Cost/Light Weight Reflector Panels-Foam Glass, Sheet Molded Compound, Graphite Fiber, Thin Film**
    - **Advanced Glass/Metal Structures**
    - **Plastic-Enclosed Structures**
- **Power Conversion Units**
    - **Solarize Automotive Ceramic Brayton**
    - **Ceramic Heater Head for Automotive Stirling**
    - **Improved Thermal Efficiency High Temperature Cavity Receivers**
- **Modules/Systems**
    - **Autonomous System controls**

Figure 4. Parabolic Dish Technology Research and Development Needs

In addition to performing technology base R&D it is necessary to perform a system field experiment. This experiment would take advantage of the Israeli R&D experience, develop an understanding of the approaches to addressing site specific problems, provide information needed by the private sector so they can consider scale-up to commercial installations, and provide feedback to identify needed technology base R&D.

R&D needs can be divided into two areas. (See Figure 5) The first area includes the pond and the equipment required to operate and maintain it. The second area includes the conversion hardware, the heat exchangers required to extract hot brine from the pond and transfer it to a working fluid, and the system controls.

The pond-related R&D will provide both a needed U.S. technology base as well as the methodology required by industry to address site specific problems. The conversion, heat extraction, and system control R&D should first identify subsystem performance and cost targets, and then focus on high-leverage technology advances specifically required to reduce the cost of electricity from solar ponds.

## II. TECHNOLOGY DEVELOPMENT - A NECESSARY BRIDGE TO COMMERCIAL USE

Technology Development (Figure 1) is an important part of the R&D spectrum of activities. The technology base area is one in which the Federal government can appropriately provide sponsorship, particularly in long-term, high-risk, and potentially high-payoff research areas. The product development and commercial applications activities are clearly at the industrial applications and commercial exploitation end of the spectrum of activities. I consider technology development to be a "technology bridge" between the Technology Base activities and the Product Development and Commercialization activities. It is important not only to consider "Technology Development" as a bridge, but also as a separate category of activity. This area of activity is frequently overlooked by people planning and proposing work in Technology Base activities. It is also frequently an area which cannot be adequately supported by industry involved in developing new technologies whose widespread application, while being potentially highly desirable from a national benefit point of view, do

- **Hydrodynamics**
  - **Surface Wave Suppression**
  - **Hot Brine Extraction and Limits of Operation**
  - **Gradient Zone Control**
- **Ground-Brine Interaction**
  - **Micro-Biological Activity**
  - **Long-Term Behavior of Sealing Clays**
- **Water Clarity**
  - **Measurements and Standards**
  - **Salt Precipitates**
  - **Mud-Brine Reactions**
- **Corrosion and Biofouling**
- **Evaporation Control**
- **Power Conversion Equipment and Heat Exchangers**
- **Automated Operations**
- **Instrumentation**
- **Large-Scale Field Experiment**

Figure 5. Salt-Gradient Pond Technology for Electric Applications -- Research and Development Needs

not presently show clear cut financial benefits from a private sector point of view.

Technology Development activities, particularly those in the system development and field test areas, are important because the research and development needs of systems-related technologies are identified and addressed only in this phase of R&D. Besides providing a focus for the critically important systems technologies, a systems field test provides feedback identifying the value of R&D activities in the technology base.

An important distinction should be made between systems field experiments and "demonstrations." Field experiments should have the following characteristics:

1. Appropriate size and site. They should be only large enough to expose unknowns and reduce uncertainties associated with scale-up to acceptable levels and sited so as to expose the hardware to appropriate environmental conditions.

2. Modular and flexible. The experiment design should permit flexibility so that unexpected problems can be overcome in the test and operations phase.

3. Test and operations plan. The test and operations plan should satisfy not only the needs of researchers, vis-a-vis providing data to compare with results of analysis, laboratory and small-scale experiments, but also the needs of industry, vis-a-vis scale-up and comparison of data to design methodologies.

4. Instrumentation. Instrumentation must be defined and developed to provide the quality and quantity of data needed to satisfy both research and industry application requirements.

5. Analytical Models. Models and methodologies must be available and applied prior to the test and operations phase so that confirmation of models or exposure of deficiencies is assured.

6. Information dissemination. Information dissemination about the field test concept, design, test and operations, data availability and data interpretation should be planned early and should include research and industry users.

## III. R&D IMPLEMENTATION CONSIDERATIONS

In addition to identifying R&D needs in the technologies, I believe the discussion of some considerations associated with R&D implementation is useful.

Once past the basic research stage, technology R&D activities require effective multi-year planning with adequate consideration given not only to the research base upon which the technology development depends, but also to industry needs for information and support. Industry input is required in the planning process. However, it is necessary to assure that the broad and often diverse spectrum of industry interested in a particular technology is accommodated. I believe that the combined strengths and talents of large companies with extensive financial and engineering resources, and smaller companies with innovative ideas are required to support the efficient development of any new technology. Frequently the interests of companies of such diverse characteristics are far from congruent. The R&D planning must recognize and allow for this.

Solar Electric Technology development activities should be goal-oriented and focused on the ultimate ability of the technology to be a significant economic resource in a utility grid-connected environment. From a broad goal statement, specific performance targets must be identified for the R&D activities. These targets are important tools for R&D management which assist in progress evaluation and resource allocation.

In entering a partnership between the public and private sector, it is important to distinguish roles and responsibilities. The responsibility of the private sector is to select those technologies which are commercially viable. When justified on some basis of public benefits, public support should be provided to advance those technologies which have the potential for commercial viability. Technologies which do not presently have that potential should be relegated to research where resource allocations are made in a different way.

R&D planning must be technology specific. It is not possible to recommend a single approach which will cover all of the technologies. A number of items need to be considered, including the state of the particular technology, its prior history and prior R&D activity, the level and direction of private sector interest, and the economic and institutional factors which affect private sector commitment of resources. The lack of appropriability of work performed by a private company often inhibits doing that particular work, no matter how necessary. Factors such as this lack of appropriability require a private sector/public sector dialogue so that efficient planning and resource allocating can be accomplished.

## IV. SUMMARY

I have tried to identify a number of R&D needs, to discuss the particular area of technology development which I believe needs special consideration, and to highlight some considerations associated with R&D implementation. I have commented on the importance of having a goal-oriented activity and of providing appropriate balance across the R&D spectrum of activities. These are not easy ends to achieve. In recognition of this it is necessary to assure that the resources required for effective planning and management effort are provided. Finally, broad consideration of industry needs in the planning and assessment process, as well as industry involvement in R&D implementation, is necessary for the efficient use of public resources.

Thank you for the opportunity to present my ideas to you today.

Marshall E. Alper

Mr. FUQUA. Thank you very much, Mr. Alper.

We have a rollcall vote, and we will stand in recess for a few minutes while we vote. We will try to resume in a few moments.

[Recess taken.]

Mr. FUQUA. The subcommittee will resume.

You had concluded, had you not, Mr. Alper?

Dr. ALPER. Yes, sir.

Mr. FUQUA. Thank you very much.

Dr. Hubbard, what budget and staff levels do you believe are needed over the next few years to keep SERI's R&D activities functioning at a rather healthy level?

Dr. HUBBARD. We spelled out some detailed numbers in our institutional plan. They may have been a bit optimistic, and we are looking at those again.

The guidance we have from the Department assumes $200 million in $40-million increments over the next 5 years, with the caveat, of course, that that is subject to the approval of the Congress.

In designing the transition plan for SERI, the plan that took SERI from the configuration it was in 2 years ago to its present research configuration, we said that we felt we could run an effective Solar Energy Research Institute with 1981 dollars in the range of $35 million to $50 million, the major uncertainty being in the amount of subcontracting we do.

New budget authority for 1983 in the mid-40 millions would put us in good shape, and we would hope to be able to maintain staff at that level through the next 4 years. If we can do that, I think SERI will be very effective.

Mr. FUQUA. What is your staffing level?

Dr. HUBBARD. We have 520 permanent people now. We are carefully strengthening that a little bit, so we would aim at full-time equivalents of a little over 600 and permanent staff in the range of 520 to 550.

Mr. FUQUA. Do you believe that for the current fiscal year, 1982, the photovoltaics program is properly balanced between advanced research, technology development, and systems R&D?

Dr. HUBBARD. There is some confusion in the terminology that obscures the issue from time to time. I think when you look at the program in terms of balance of activities, it balances out reasonably well.

Mr. FUQUA. Dr. Schueler, at Sandia, in photovoltaics, you are primarily concerned with trying to reduce the systems cost. What are the principal factors keeping the balance of the systems costs high, and why can't they be brought down?

Dr. SCHUELER. Mr. Chairman, I believe that, in fact, the balance of system cost can be brought down. It is a matter of developing the proper approaches to balance of system, and by balance of system I mean the total cost of deploying a photovoltaic collector field and integrating that into an overall power system that will produce electrical energy that is compatible with utility applications.

The major cost that we have experienced—and this experience comes from fielding a number of application experiments over the past few years—comes from approaching the balance of system in a conventional architect engineering way which results in very high installation costs of the collector field in terms of wiring and cabling and foundation and structure costs. Based on the experience in those first application experiments, we have developed designs for collector fields that we believe will be cost effective and will meet target costs for complete installed collector systems. Basically, you have to be very careful to reduce the amount of field labor in installing photovoltaic systems, in the design conservatism that is applied to collector fields, and finally in the amount of material such as concrete and steel that is used to deploy collector systems.

Again, I believe that we have developed and are in the process of fielding a very limited number of prototype designs that will demonstrate the ability to get balance-of-system costs to target goals. A second major cost item in balance of system is the DC to AC inversion process, which is required to convert DC electricity as it is generated by a photovoltaic collector into AC electricity, and again in that area we have developed a great deal of experience through the first application experiments and are in the process of developing and testing second-generation conversion hardware that will provide adequate performance and efficiency at again, we hope, target costs for this kind of equipment.

Mr. FUQUA. Why won't private industry pick up those initiatives?

Dr. SCHUELER. Again, it is a matter, I think, of risk and the proper timeframe. Given an existing demand for this kind of equipment and given time to develop the kind of equipment, private industry in fact on its own, I believe, could develop this kind of technology and this kind of hardware.

I think, though, also, it is important for the Federal Government to take a lead to demonstrate through prototype hardware that it is possible, that it is not an impossible situation, especially with regard to the collector field balance-of-system cost; that some new attention needs to be given to techniques which are outside the conventional practice of architects and engineers in terms of designing structures and wiring systems, and so forth, and in fact most of the work that is being sponsored by the Department of Energy program in photovoltaics is being conducted through the use of private industry.

Mr. FUQUA. We have had industry testify that it believes that the parabolic trough technology does not require any further Federal funding, whereas you indicate in your testimony that collector development and cogeneration systems require further R&D.

How would you explain this difference between what you believe and what industry believes?

Dr. SCHUELER. Well, on the other hand, I have had very direct indication from the industry that they do see a number of profitable things that could be done, could be sponsored, undertaken by the Federal programs, that would help them very directly, such things as advanced lightweight composites for parabolic trough reflectors, in the area of testing, long-term durability testing, that involves attempting to accelerate failures, accelerate wear on collectors in a very controlled way, and in the area of producing higher temperature, more stable working fluids and absorbers.

I believe that the current industry serving the current market is in good shape in terms of its ability to incrementally improve its product and to sustain a viable, ongoing industry. But when we talk about solar electric applications for parabolic troughs, which is the subject at hand, I think there are a number of significant advances that are needed in the technology. Most of the commercial market and most of the experience to date in the parabolic trough area has been for industrial process heat applications, which involve much lower temperatures and are not as critical in terms of their operation as the higher temperature requirements for solar electric.

Mr. FUQUA. Mr. Alper, how have the photovoltaic firms that you deal with responded to the budget cuts in the DOE photovoltaics program? Have they increased their efforts to compensate for that reduction?

Dr. ALPER. I think, Mr. Chairman, the question of how firms respond has to be disaggregated. As you are aware, the Laboratory has had over 100 private sector contractors participate in the program. Some of the larger contractors, I believe, still feel that there are certain engineering science activities that could profitably be carried on. Their feelings tend to focus on some of the near term to midterm activities, however, as opposed to some of the far term activities which have been discussed.

A large number of the smaller firms, I believe, would have a very difficult time if Federal support were withdrawn. They do not have substantial financial resources of their own, and they do not yet have enough of a market to be able to support their inhouse R&D out of profits.

Mr. FUQUA. What level of effort is required over the next few years—say 5 years—to maintain an adequate technology development program for photovoltaics or for the parabolic dish?

Dr. ALPER. On both of those areas, sir, we provide the Department of Energy with a number of different options, and it clearly has to be their responsibility to provide us guidance in terms of what level they would like us to propose a program.

Answering your question is clearly very difficult. It depends on not only the total level of effort, how much should properly go to SERI and how much should properly go to Sandia, as well as clarification of the question of how soon, in fact, does the administration and the Congress want to see some of this technology become viable.

Mr. FUQUA. Mr. Skeen?

Mr. SKEEN. Thank you, Mr. Chairman.

I wanted to ask Mr. Schueler of Sandia a question. In your testimony, you indicate that there is a need to provide a balanced solar program, emphasizing both basic research and systems activities. What are your plans with respect to funding of these test facilities that have been built in the solar thermal and photovoltaic programs, such as the central receiver test facility at Sandia and the photovoltaics PRDA experiment? What would happen if these funds were terminated?

Dr. SCHUELER. At the present time, those facilities are continuing to be operated. We do have plans in place to continue to operate those experiments, first the PRDA experiments that you mentioned, through at least a full year of operation, and funds for that have been provided in the fiscal 1982 budget.

With regard to the test facilities at Sandia Laboratories, which include the central receiver test facility, a distributed collector test facility and the photovoltaic test facility, the continued operation and existence of those facilities is contingent upon the 1983 budget.

Mr. SKEEN. Thank you.

Mr. Schueler, what do you estimate that you will need in 1983 for these facilities to insure their continued operation?

Dr. SCHUELER. With regard to again first the PRDA experiments, as I said, those experiments basically have been funded in their operational phase with 1982 funds. We see some small level of continuing effort in 1983 being required to keep the necessary technical staff to oversee those experiments and to provide perhaps some augmentation or upgrading of selected experiments.

The cost of doing that is on the order of a couple of million dollars in fiscal 1983. With regard to the experimental test facilities at Sandia Laboratories, those facilities are used to support and respond to the ongoing research and development activities, and so the requirements for those—that is, the level of their activity—depends very directly on the size of the overall DOE solar program and the scope of activities in that program. So it is very difficult to give you a specific dollar figure with respect to supporting those facilities because, again, what they do depends on supporting the overall solar program, and its size depends on the activities required.

Mr. SKEEN. Yes, I understand. Thank you, Mr. Schueler, and thank you, Mr. Chairman.

Mr. FUQUA. Thank you very much, Mr. Skeen.

I would like to say to our witnesses that we may have some more questions that we would like to submit to you in writing. If we do, we will submit those to you very shortly.

Thank you very much, and we appreciate your being here with us this afternoon.

Mr. FUQUA. Our next panel is Roger Little, president of the Spire Corp. in Massachusetts; Dr. T. W. Fraser Russell, the Institute of Energy Conversion at the University of Delaware; and Dr. John Schaefer, the manager of the Photovoltaics Division of the New Mexico Solar Energy Institute at Las Cruces, N. Mex.

We are very pleased to have you gentlemen here. Mr. Little, we will begin with you.

We will make your statements in their entirety part of the record. If you wish to summarize, we would be very pleased for you to do that.

## STATEMENTS OF ROGER LITTLE, PRESIDENT, SPIRE CORP., BEDFORD, MASS.; DR. T. W. FRASER RUSSELL, INSTITUTE OF ENERGY CONVERSION, UNIVERSITY OF DELAWARE, NEWARK, DEL.; AND DR. JOHN SCHAEFER, MANAGER, PHOTOVOLTAICS DIVISION, NEW MEXICO SOLAR ENERGY INSTITUTE, LAS CRUCES, N. MEX.

Mr. LITTLE. Thank you, Mr. Chairman.

I am president of Spire Corp. We are in Boston, Mass., in the area. I have about 100 people. We do advanced R&D leading to processing equipment for photovoltaics, so our business direction is to manufacture processing equipment, to manufacture solar cells and modules.

We participated in the DOE photovoltaic program for a number of years going back in its entirety, perhaps 8 years before it became DOE.

The points I will try to make are that photovoltaics is an exciting technology which has both long-term energy impact markets with also the possibility of nearer term markets, and that it is necessary to keep the industry as it exists healthy in the near term so that it can play a major role in the longer term.

Right now the industry is very fragile. No one is profitable. There is no public investment available. There is some private investment, but it is not sufficient to pick up and carry the role necessary to solve the R&D problems that we have, to become a viable, profitable industry.

To make my points, I would like to go to some vugraphs.

[Slide shown.]

My argument for the need for Government help to solve some of these R&D problems is based principally on this graph which shows growth versus time, product growth stages versus time. Now, this is typical of a lot of high technology industries.

As far as photovoltaics is concerned, an important thing to see is that it may be a 15- to 20-year period of time before it impacts the grid, before it has a significant energy impact.

The stages of the growth curve again are common for photovoltaics as other technologies. First there is a scientific discovery, and the discovery leads to grand predictions: The discovery is going to solve a lot of problems, it is going to solve our energy requirements, and so forth.

Very soon thereafter, these discoveries go over the grand prediction curve, down into the problem area. We find out what the realities of the situation are, how difficult it is to implement the technology, and in some cases, some of the ideas go right through the bottom of the problem trough and are no longer pursued.

In other cases, you go through a slow progress period which can last as long as 5 years or more. This is significant, as I will point out later, because most investment does not want to wait that long to have a successful corporation.

I want to use this curve to show the status of the technology from a subjective point of view, what the Government's role has been, what industry's role has been, talk about some prospects for public support, and make some recommendations for R&D.

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[Slide shown.]

This is not covering all the technologies that are being investigated; however, some representative ones are shown. You can see that they fall at different stages along the PV product growth curve. There are some new ideas which are coming out in the discovery and grand prediction phases. Some of the things indicated there are multijunctions, alloyed amorphous silicon thin films.

Then there are technologies which are in the problem trough, and again it is subjective, perhaps amorphous silicon, thin-film gallium arsenide. Ribbon materials are further along; cast materials, still further along. The only thing that can be considered in a low-level production phase at this time is Czochralski silicon. This is climbing up the learning curve.

But a major point here is that most of what is going on in photovoltaics falls in this problem area. The utilities have done analyses to indicate that you have to have 15- to 16-percent modules in order to impact the grid. These have to be at very low cost. In order to achieve what they want, we probably have to reduce the cost of modules a factor of 10, increase their efficiency a factor of two, and increase their lifetime a factor of three.

The low-level production area is important for near-term markets and healthy industry, and that is an area that should not be ignored as well.

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This is what Government involvement has been in the past. This is what got the industry to where it is today. Approximately $400 million has been invested in photovoltaics since the DOE program began.

In the discovery and grand prediction area, it is primarily the role of SERI to take new ideas, to bring them to a point where they appear feasible for implementing; then there is a transition. Such ideas which have come through the SERI process go into a technology development phase. This has been primarily the role of JPL with Sandia's support. Then, finally, things went into demonstration projects. I think everyone agrees that demonstration projects are totally the role of industry.

However, with the chopping back of the budget, we tend to chop the activities from right to left across the curve. We are chopping through the technology development back toward the advanced R&D. Now, that is really a tough area, and it is the area the industry really needs a great deal of help in right now.

It has been estimated that it would take another $400 million to achieve some of the goals we have for photovoltaics. A typical industry today does not invest more than 10 percent of its gross revenues in R&D. This would require a $5 billion industry. No way is our industry near that level.

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[Slide shown.]

I just want to point out, in my estimation, the best performers along the PV growth curve. Initially, in the innovative phases, Government laboratories, universities, big company laboratories play major roles. It requires in some cases some very sophisticated equipment. It requires staffs which are stable, that can pursue some of the basic research areas.

Small companies and medium-size companies tend to fall in the problem trough area. The more innovative tend to get to the market first, find market niches, and really bring on line a nearer term industry.

In the long term, we have the major energy corporations, and we have oil companies to thank for some significant investment in photovoltaics today. Their perspective, however, tends to be toward these longer term market and market share rather than market niches in near-term profitability. I maintain some near-term profitability is necessary for industry to be healthy enough to take over some of this R&D.

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[Slide shown.]

Based upon my experience, public investment is extremely difficult to get in photovoltaics. In the discovery and grand prediction phases, there are things like R&D limited partnerships. These things tend to be limited to very big investments.

Venture capital, sometimes you can get them interested down there with new ideas. However, it is very rare today to get venture capital investments in photovoltaics. No one is interested at all in the problem and slow-growth phases of activity. No one will invest in that area.

Stock issues are really out of the question. Basically, the whole public investment picture wants return on investment in 3 to 5 years. We in the energy business recognize a much longer period before we can make significant profits; therefore, there is no public investment to pick up the funding required in order to move the technology along further.

I would like to summarize by saying that the industry is fragile; it is not ready to pick up the ball from Government. There are really no public dollars available. There are some private dollars, but not nearly enough, and we are really going to need the help of the Government to carry us through these difficult, problem-trough, slow-growth phases of photovoltaic technology.

Thank you, Mr. Chairman.

Mr. FUQUA. Thank you very much, Mr. Little. Dr. Russell?

Dr. RUSSELL. Good afternoon. I am much appreciative of this opportunity to address this important committee of the House of Representatives and bring to your deliberations the experience of one of the major university-based photovoltaic research and development activities in the States.

My name is Fraser Russell, and I am the Allan Colburn professor of chemical engineering and the director of the Institute of Energy Conversion at the University of Delaware.

The Institute of Energy Conversion is a research laboratory which has been devoted to the development of thin-film photovoltaic cells, and we have just moved into a new 40,000-square-foot laboratory specially designed to carry out this research.

We have a staff of about 20 professionals and 25 technical support staff. We augment this number by faculty, graduate students, and undergraduate students from various departments of the university, visiting scientists and postdoctoral students.

The research effort is supported with about $1.3 million of Federal money administered through DOE and SERI and approximately half a million dollars of funds from various industrial concerns.

The Federal Government's funds are used in a basic research program for design, synthesis and analysis of electronic materials, photovoltaic device design and analysis and device development. At the present time, we are working with four material systems.

Industrial funds are used for a fundamental engineering research effort which we have entitled photovoltaic unit operations. This fundamental engineering effort is necessary, in our view, because the information needed for the commercial-scale design of photovoltaic cell manufacturing facilities cannot be obtained from bench-scale laboratory experiments.

It is our opinion that thin-film cells are more like a chemical product than they are like an electronic device. We must make large quantities at low cost.

Our view is rather a long-range one. In carrying out our research and education efforts over the past decade, we have produced 40 professionals, now working in the growing photovoltaic industry, who received all or at least part of their education at the University of Delaware.

Now, in 1978, the Congress of the United States committed the Nation to an aggressive program—development of solar cells—when it passed the Solar Photovoltaic Energy Research, Development and Demonstration Act. Congress made a wise decision in 1978, and those of us who try to meet society's needs through fundamental scientific and engineering research set up laboratories, purchased equipment, and engaged personnel to meet the goals defined by the act. At the University of Delaware, we committed ourselves to a photovoltaic research program in 1972. We made a specific decision to carry out research on thin-film, low-cost solar cells, and we did so because we felt that thin-film cells would provide for the production of electricity from photovoltaic systems cost competitive with utility-generated electricity from conventional sources.

I am sure you recognize that conventional sources such as coal and oil are in fact solar energy which has been stored in a particularly convenient form. To use the Sun directly—and now I am talking again long range—very large areas of cells are required. To meet the Department of Energy's projected demand for one quad of PV electricity in the U.S.A. by the year 2000 will require 620 square-miles, or 1,600 square-kilometers of photovoltaic cells.

Today's embryonic photovoltaic industry must mature from the single crystal silicon cell, high-cost manufacturing operation, to a mature thin-film cell, low-cost manufacturing operation, probably using a variety of different material systems. To do so, we must have Government research support—its long-range, high-risk type of support.

The thin-film research effort to date which is now beginning to attract some private funding has been adversely impacted by uncertain and, in recent years, declining Federal funds, and has not been sufficient to meet the major goals that Congress set when it passed the Solar Photovoltaic Research, Development and Demonstration Act.

I think it is necessary to implement Congress plan. It is an essential part of a rational energy policy for the United States. We cannot keep drawing on our bank account of stored solar energy without someday paying a very great penalty. Balancing our energy budget is as essential as balancing our national fiscal budget. I am assuming you know more about that than I do. We have enough energy from the Sun; we need the research and capital investment to collect it efficiently, and we need stable, multiyear funding to do so.

The potential is very great. If we can manufacture thin-film photo cells, the total capital cost for putting them in a power generation facility is around $1 per watt. That figure represents a reasonable extrapolation of what can happen if the research and development are performed. At that capital cost electricity to the consumer can be provided at a cost between 5 and 15 cents a kilowatthour, depending upon how one carries out the detailed economics. That is a pretty good potential, and it is well worth the investment in research and development.

To carry it out, we need money and people with appropriate education. We need an integrated research plan which combines fundamental studies of new and existing material, creative device design, and, most important, at least in my view, we need imaginative fundamental engineering to assure that low-cost manufacturing can be achieved. We are not interested in square centimeters; we are interested in millions of square meters. There must be a continuous interplay among these different phases of research and development.

If there is not, there can be no assurance that the laboratory experimentation will be adapted into commercial scale production technology. We must be able to produce millions of square meters. If you leave the research in the hands of bench-scale scientists, they will keep it in the laboratory. At some point, you have to have a means to get it out of the lab and make it available to the public.

Now, I think we need research into a number of different material systems. Within the past decade, we have looked at 20 different systems. At the present time, the number of thin-film systems is much less. We have research in this country in amorphous silicon. Funds have been provided by DOE and SERI, RCA, Energy Conversion Devices and, more recently, Chronar.

Two methods of making the film have been devised, and cell efficiencies of 10 percent have recently been announced. RCA just announced that they have made a 10-percent amorphous silicon cell, and it was with some pride that we can tell you that that achievement was made with a young scientist who was with the Institute of Energy Conversion for a number of years.

An intensive effort to develop the commercial-scale production facilities is being carried out in Japan, and they are building upon our fundamental research effort.

In the Cu2S mixed sulfide cell, research has been supported by DOE/SERI, Shell Co., through their subsidiary, SES, Chevron, and Photon Power, and there is a significant research effort in Europe.

There are two methods of now producing the cells. One is in small-scale commercial production, and the other is an area of active production-scale research. Cell efficiencies of just over 10 percent have been achieved, and some recent research into cell stability has produced promising results. Methods of continuously depositing the active semiconductor layers on moving substrates have been developed which produce cells within 1 percent of the efficiencies made in the laboratory.

There are various other systems, including copper indium diselenide and cadmium telluride which have been developed.

That is a reasonably significant return on a Government investment that has been well under $100 million for thin films. Industrial funding is estimated to have been on the order of $20 million to $30 million. Although this is far less than originally mandated from Congress, considerable progress has been made in the technology, certainly enough to justify further funding.

The written documentation provides in detail some of the advances that we have made in efficiency, stability, basic research, and commercial development.

We must continue, however, to do this kind of research. We need to do research in established materials. We need to do research in new materials. I think we need to keep our eyes on the photovoltaic unit operations side of the research to make sure that we get out of the laboratory at the millions-of-square-meters scale.

I would like to see us implement Congress plan and support PV research with multiyear funding, thin films in particular. Under whatever budget cutting must exist, I think it is terribly important as a Nation that the university programs must be kept going. Unless we are willing to admit that there is no sense in doing photovoltaics, at the very least, we have to keep programs alive at the university; otherwise, we will not have the educated people that are necessary to carry out and make this industry grow.

I think energy planning is essential. I think some of the planning from the national laboratories has been very good, but they do not necessarily have all the answers. We would like to see some flexible funding come directly to the universities.

Thank you.

Mr. **Fuqua**. Thank you, Dr. Russell.

Dr. Schaefer?

Dr. **Schaefer**. Mr. Chairman and members of the subcommittee, I am very grateful for this opportunity to air my views on the existence and level of support of the national photovoltaic program of the Federal Government.

Mr. Skeen has already introduced me, so I will not take your time with that.

I would like to summarize my opinions as follows: The first point is that terrestrial PV systems work. The second point is that eventually they will become cost effective relative to other energy forms, whether or not there is Federal support. Therefore, eventually, terrestrial PV systems will make substantial contributions to our energy supply, independent of Federal support.

The fourth point is that, despite that, I feel that Federal support is terribly important. Fifth, the form of that support should be a balanced program of basic and applied and what I will call developmental research.

Now, if you accept my first two points, then the third one, that eventually PV systems will make substantial contributions, follows. With your permission, I will spend my time on the last two points.

Why Federal support? Because I believe it will substantially hasten the time of our energy independence from other nations. I do not think I or anyone has an absolute value of what "substantially" means, but I can guess about 10 years, and I believe that is terribly important. I believe it will substantially reduce this Nation's and the world's consumption of fossil fuels.

Our current thrust seems to be to speed up the rate at which we find and extract our fossil fuels. It makes absolutely no sense to me. It only moves ahead the time at which we run out of them. Every day the sun deposits more energy on this Nation and on earth than we or the rest of the world use. It would seem to me that our absolute first priority should be to develop usable ways to make use of that energy. This Nation should be first in that.

We are less of a hostage now than we were 10 years ago, principally because we had the wits scared out of us. We import less oil than we did, partially through conservation efforts, partially through use of other fuels. I think we just made a small dent. The dent is too small, and it is not growing fast enough.

With respect to continued support of our own PV industry, our industry is the world leader right now, and I don't think it necessarily will fall from that position in the absence of Federal support. You heard of a substantial investment lately. The investment overseas has been greater than that, I am told, by both our industry's competition and by their governments.

I believe it to be crucial that we not go from a Nation that relies on foreign oil imports to a Nation that relies on foreign alternative energy products and components. There has been a lot of concern in the last few years about Japanese penetration of our automobile industry. I suspect there would be far greater concern 20 years from now if the Toyota and Datsun electric automobile in your garage were powered by a Sanyo or Hitachi PV array on the roof of your house.

I support a balanced program—some basic, some applied, and some of what I will call developmental research to reduce the risk of fielding systems. Other witnesses here supported the applied or advanced research, and they are more qualified than I. My experience is as an evaluator of systems out in the field. In fact, almost the entire staff of my division of the Solar Energy Institute is involved in the evaluation of fielded PV systems, systems that turn out usable energy.

We and other facilities such as the ones we are involved in have proven that they work, but we have not proven that they are workable, particularly that they are workable for 20 years. I submit there is no substitute for long-term testing.

I believe we must continue to tie new products as they evolve into working systems, evaluate them, report the results back to industry, to program management, and to the consumer who is waiting out there. Our function is to identify the good and bad things, the phenomenology that we observe, good components and good ways to tie components together, and get the results back to people. There are many of them out there waiting for that $2 per watt PV system.

Facilities such as the Southwest Residential Experiment Station, or Southwest RES as we call it—it has a sister facility in the Boston area—are unique. We can do systems tests there that no one else can, that neither the electrical utilities nor the PV industry have seen fit or perhaps can afford to establish.

I would like to give you an example of an experiment which we have conducted which has attracted some attention, especially among the utilities. We postulated that when a number of small electrical cogenerators are tied together—we didn't know what the number was—nonetheless, when a number are tied together on a utility distribution network, and if the number or the size is great enough that the aggregate production of that batch of cogenerators is equal to the aggregate load in that same distribution area, then it would be possible for the serving utility to go away, to shut down, to have a line break, and yet these cogenerators would keep right on running, even though there are not supposed to, even though each utility in the Nation that I know of requires that cogenerators shut down when a utility goes away.

We conducted a test to prove our postulation. It involved a small number of inverters, a very small area, very controlled conditions, but I believe we proved the point. What we did attracted a lot of attention among the utility people that we disseminated the results to. Many of them have shown a lot of interest, have asked us to expand on this effort, to define the parameters and the bounds by which this process could be repeated in the real world.

Again, the important point is that, to the best of my knowledge, there is no privately funded facility that could have done such an experiment, certainly not without a lot more investment than most of them are either capable of or willing to undertake.

For that reason and for many other reasons, many of which I have listed in my written testimony, I believe the kind of work that the Southwest RES, the Northeast RES, and similar facilities can do is very vital to speeding up the time at which workable photovoltaic systems get out in the field and make a measurable impact on reducing the rate at which we and the rest of the world consume our nonrenewable fuels.

I believe it is necessary to continue to protect the public from unworkable systems, systems that are not going to work the 20 years that is required to be cost effective in most cases. By those processes, I believe we can do a great deal to insure public acceptance. Heat pumps were introduced back in the late forties before their time; they got a bad name. It took heat pumps something on the order of another 20 years to finally be publicly acceptable as indeed they are now.

I believe it crucial that we avoid that kind of stigma with photovoltaics because I don't think photovoltaics deserves it now or ever will. I believe our goal should be to insure that, however. Thank you.

[The prepared statements of Mr. Little, Dr. Russell, and Dr. Schaefer follow:]

## STATEMENT OF ROGER G. LITTLE OF SPIRE CORP., CONCERNING RESEARCH NEEDS FOR SOLAR ELECTRIC TECHNOLOGIES

### 1. INTRODUCTION

Photovoltaics is unique in that it has near-term economic benefits as an exporting high technology industry while offering the possibility of major energy impact in the longer term. An industry which is profitable in the near-term markets is more likely to succeed in achieving longer term goals. Therefore, research activities which address the needs of both near and long term industry and markets are required. This is especially true since the photovoltaic industry is fragile. Almost no one is profitable, in the free market sense. There are currently few public investment dollars available. Private support is principally by the oil industry and today's oil industry climate is not favorable to PV. Government involvement is therefore necessary if the industry, as it exists, is to survive, grow and ultimately prosper.

### 2. PV PRODUCT GROWTH STAGES

The argument for the need for continuing Federal participation in the PV industry is based upon the curve of Figure 1 which shows PV Product Growth Stages versus Time. This growth curve originated from a study done by L. A. Murray, published in Electro-Optical Systems Design, October 1981. Murray evaluated a number of electro-optic technologies and determined that their development from Discovery to the Mature Market stage followed an approximate 15-year cycle. The PV Product Growth Cycle is likely to be even longer than those of the electro-optic technologies. The figure shows a 15 to 20 year PV cycle. It may even extend beyond that for significant energy impact.

The major phases of growth, presented in the figure, are as follows:

Discovery — an idea is conceived or discovered.

Grand Predictions — the idea is perceived to be a sure technical and economic success.

Problems — as the concept is further pursued, problems associated with its implementation are identified. In most cases, the idea never recovers from the problem area and in time is dropped.

Slow Progress — for those technologies which do not clearly fail and have ultimate significant commercial viability, the problems are attacked and slow progress is made.

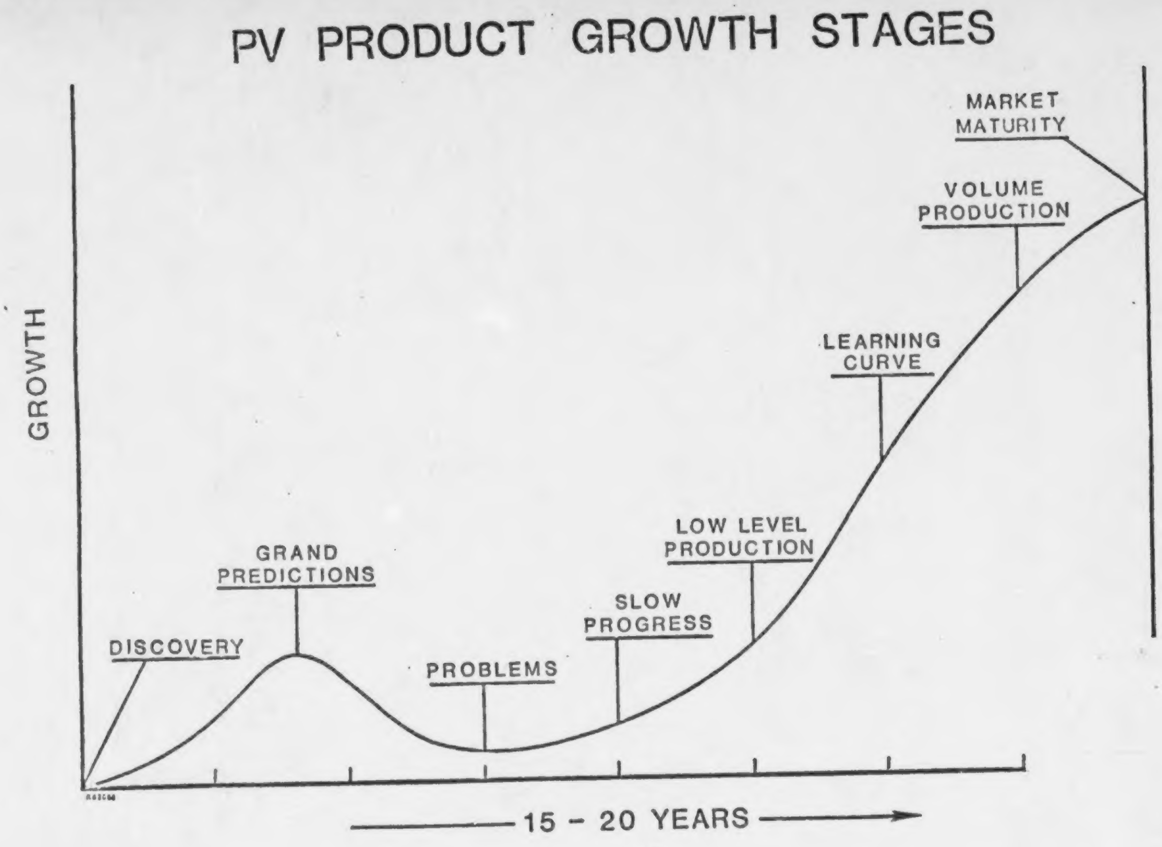

PV PRODUCT GROWTH STAGES
GROWTH
MARKET MATURITY
VOLUME PRODUCTION
LEARNING CURVE
LOW LEVEL PRODUCTION
SLOW PROGRESS
PROBLEMS
GRAND PREDICTIONS
DISCOVERY
15 - 20 YEARS

FIGURE 1.

Low-Level Production — as progress is made, low level production is implemented.

Learning Curve — through production experience, a learning curve is followed. Volume increases, costs generally come down, and market size increases.

Volume Production — here the market has opened up, production techniques have improved, and an "industry" exists.

Market Maturity — ultimately, a mature market is reached, characterized by high volume production, competition, etc.

This curve, with its various phases, will be used throughout this discussion to present a perspective on the status of the PV "industry"; PV's research needs; what government involvement has been; where public investment stands; how private investment, predominantly by oil companies, has helped PV; and what recommendations for a Federal role are made.

## 3. TECHNOLOGY POSITION IN GROWTH STAGE

Low cost must be achieved for major energy impact. The most direct path to low cost is through high efficiency because of associated "balance of systems" cost. Analyses have been performed which indicate that overall flat-plate module efficiencies must achieve 15% for widespread utilization. Currently, single-crystal silicon modules are typically 10% efficient, but are expensive. Thin-film modules, although offering the potential for low cost, are not yet in production and are closer to 4% efficient. Although subjective, Figure 2 presents a perspective of the position of various photovoltaic technologies on the PV Product Growth Stage Curve.

$CuInSe_2$ has recently moved into the Grand Prediction phase and perhaps is beginning down the Problems Slope into the "Problem Area" trough. Similarly, amorphous Si, especially alloys such as amorphous Si:Ge, might find themselves just over the Grand Prediction peak. There has been much discussion and excitement over amorphous Si, primarily stimulated by Japanese activities. However, the delay from the Grand Predictions phase to pilot manufacturing for terrestrial energy indicates that problems are being encountered. Its ultimate promise, however, has resulted in the commitment of a number of major companies to this approach. GaAs thin films have also been under

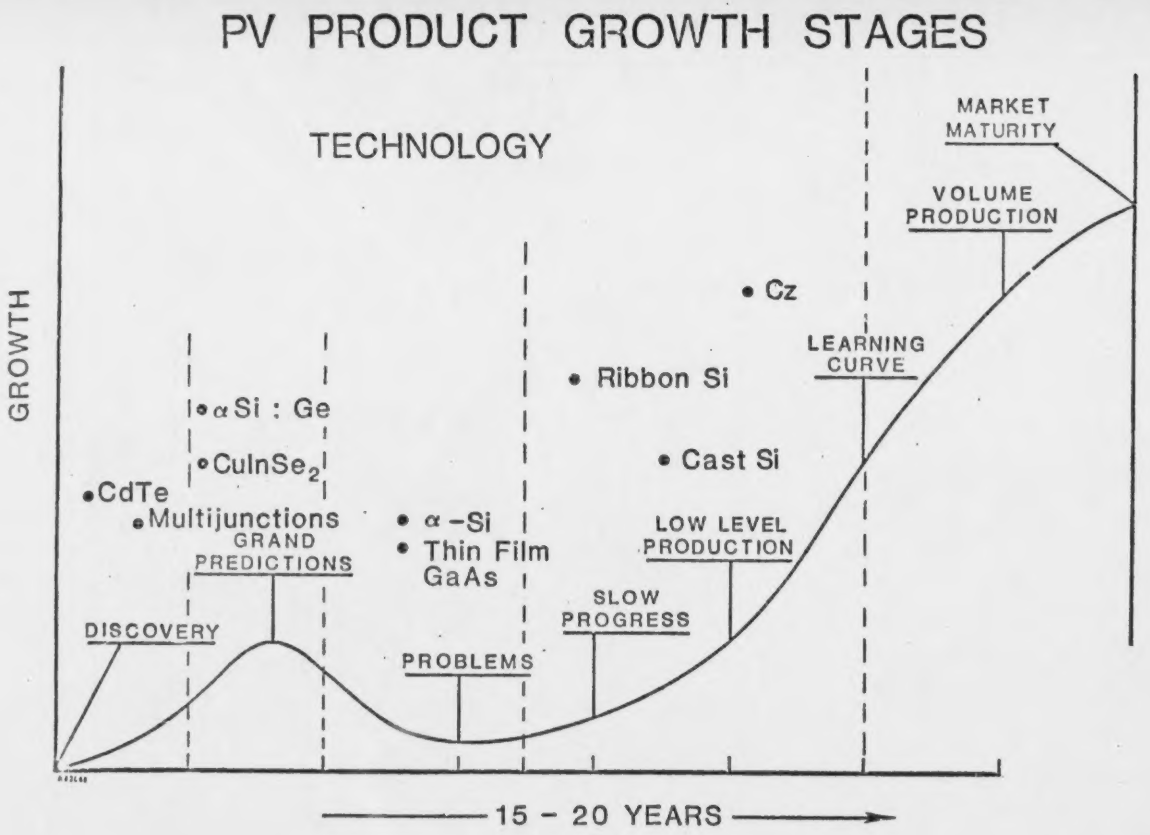

PV PRODUCT GROWTH STAGES
TECHNOLOGY
GROWTH
MARKET MATURITY
VOLUME PRODUCTION
Cz
LEARNING CURVE
Ribbon Si
αSi : Ge
CuInSe$_2$
Cast Si
CdTe
Multijunctions
α -Si
Thin Film GaAs
LOW LEVEL PRODUCTION
GRAND PREDICTIONS
SLOW PROGRESS
DISCOVERY
PROBLEMS
15 - 20 YEARS

FIGURE 2.

consideration. Their promise for very high efficiency is well known; they too are in the phase where problems associated with their deposition and utilization in thin film form must be resolved.

Progress is being made with ribbon Si approaches. Both Westinghouse and Mobil-Tyco are in pilot production on such materials, moving toward Low-Level Production. Somewhat more advanced is cast Si, such as is being pursued by Solarex with Semix. Semix is into Low-Level Production and moving up the Learning Curve. Czochralski Si wafers, the basis for most of today's module production, has proven itself for manufacturing successful product. It is the most advanced up the Learning Curve. However, its ultimate cost reduction potential is geared strongly to progress in polysilicon production.

No technology can really be considered to have achieved the Volume Production stage in the context of the terrestrial energy market. This, the ultimate market, is the one toward which major PV investment is directed.

In order to achieve Volume Production and Market Maturity, it will be necessary to produce a reliable, high efficiency module at low cost. This can be approached by either: (1) searching for a breakthrough in the Discovery and Grand Predictions area, which leap frogs today's technology, or, (2) by solving problems in the trough of the curve and expanding production according to market demands, perseveringly crawling up the Learning Curve with the participants introducing new technologies as they are developed.

## 4. PAST GOVERNMENT INVOLVEMENT

Figure 3 shows where the Federal government, through the Department of Energy (DOE), has put its emphasis in the past. There are three major areas of the PV Product Growth Stage Curve that can be identified. The first is Advanced Research and Development, coordinated by the Solar Energy Research Institute, SERI. Their activities have been primarily in the Discovery and Grand Prediction phases of the curve.

The second area of government participation has been in Technology Development, under the direction of the Jet Propulsion Laboratory, JPL. As can be seen, PV concepts deemed viable, are to flow out of the SERI program to JPL for further development. This is the toughest area of the Growth Stage Curve. It is the area of Problems and Slow

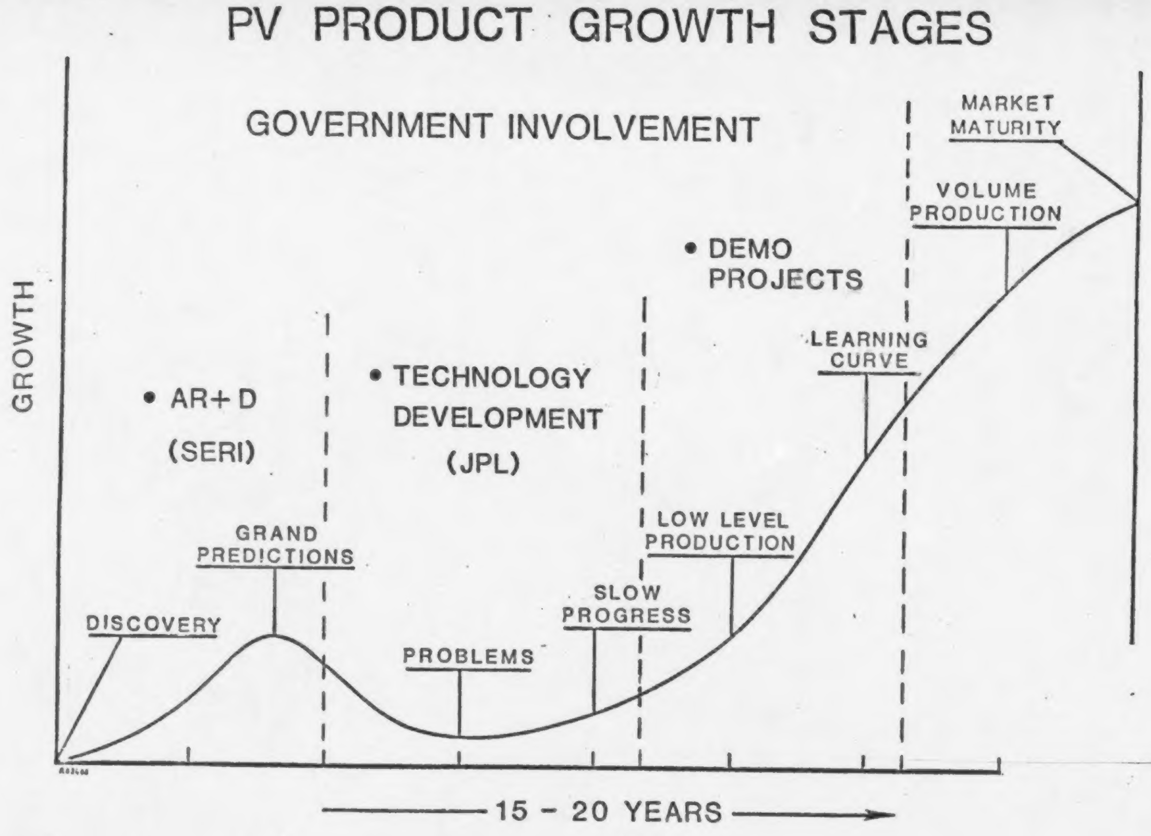

PV PRODUCT GROWTH STAGES
GOVERNMENT INVOLVEMENT
GROWTH
• AR+D
(SERI)
• TECHNOLOGY
DEVELOPMENT
(JPL)
• DEMO
PROJECTS
DISCOVERY
GRAND
PREDICTIONS
PROBLEMS
SLOW
PROGRESS
LOW LEVEL
PRODUCTION
LEARNING
CURVE
VOLUME
PRODUCTION
MARKET
MATURITY
15 - 20 YEARS

FIGURE 3.

Progress, where many ideas with Grand Predictions are weeded out. Many of the high risk approaches pursued in the Technology Development area take 5 years or more to be demonstrated to be commercially viable and ready for industry take-over.

The third major area of the growth curve is that addressed by Demonstration Projects of the past. These demonstration projects, coordinated primarily by the DOE in Washington, Sandia, and NASA-Lewis, allowed the small photovoltaic industry to achieve Low-Level Production, improve product performance, and move up the Learning Curve.

With budget cutbacks, Technology Development and Test and Demonstration Project areas are being curtailed, whereas there is more interest in continuing Advanced Research and Development activities. Reduction in the R&D efforts associated with the Technology Development area will severely hurt today's industry and make it much less competitive on an international front.

## 5. BEST PERFORMERS

Figure 4 shows the PV Product Growth Stage Curve divided into three major areas, in which "best performers" are identified. First, the Discovery and Grand Predictions phases of the curve are most conducive to basic research activities such as has been sponsored by SERI and carried out at universities as well as other organizations. This area requires extensive diagnostic techniques and equipment not often available in smaller organizations. Also, many of these areas of investigation require the continuity associated with the technical staffs of both government laboratories and large companies. Although small companies have made significant contributions to this area, in general they are resource limited and therefore not the best performers.

The middle region of the PV Product Growth Stage Curve is best addressed by small and medium sized companies. Small companies can be the best problem solvers because they are quick, clever, innovative, and they can invent on schedule when it means making payroll. They are therefore best for addressing the Problems area of the growth curve. Small companies also have the high risk attitude necessary to enter into Low-Level Production. They are the first to market and the first to ferret out the marketing niches. It is this area of problem solving and small companies which is in most jeopardy due to Federal government budget cutbacks. It is this area of PV industry activity that requires the most help, especially for competing in near-term markets.

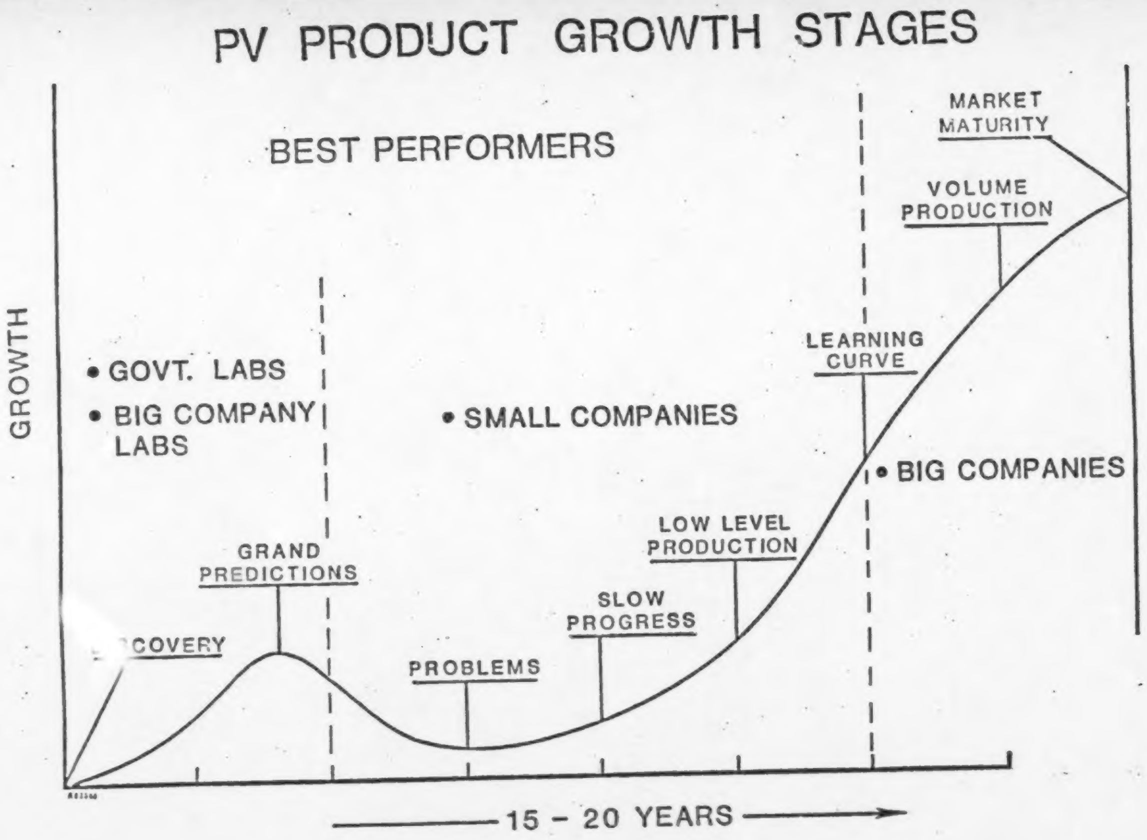

PV PRODUCT GROWTH STAGES
BEST PERFORMERS
GROWTH
• GOVT. LABS
• BIG COMPANY LABS
• SMALL COMPANIES
• BIG COMPANIES
COVERY
GRAND PREDICTIONS
PROBLEMS
SLOW PROGRESS
LOW LEVEL PRODUCTION
LEARNING CURVE
VOLUME PRODUCTION
MARKET MATURITY
15 - 20 YEARS

FIGURE 4.

Ultimately, once Volume Production is achieved, large companies perform best, especially in the energy industry. If photovoltaics are to make an impact upon the national and international energy situation, large capital investments must be made. The participation by oil companies in the PV industry is therefore welcome, especially in the Volume Production and Mature Market phases of activity.

With the Federal government cutbacks, we should now ask who will provide the resources for research to move the photovoltaic activities presently found in the Problems and Slow Progress areas of the growth curve.

## 6. PUBLIC INVESTMENT

The PV Product Growth Stage Curve of Figure 5 is divided into areas which represent when the public might make an investment. It is conceivable that such funding vehicles as R&D limited partnerships can be launched during the Discovery and Grand Prediction phases of the curve. However, trends in this area of finance are such that only very large investment situations are of interest. Also, there is less interest in R&D limited partnerships today than there was, for instance, one or two years ago due to tax law changes. Thus far, very few R&D limited partnerships in any business area have been successful.

In the Grand Prediction phase of the curve it is possible to get some interest from venture capital. Venture capital, however, has major concerns about the photovoltaic industry. Also, venture capital finds photovoltaics too complicated with too many technical approaches. No public investment appears possible in the Problem and Slow Progress phases of the growth curve because of the long time required to solve problems in this stage. These factors make it unlikely that venture capital will play a major role in the photovoltaic industry.

Public stock issues can be considered in the Low Level Production and Learning Curve areas. It is interesting to note, however, that of all stock issues in the past 10 years, oil and gas have been the most successful and alternate energy the least.

Since the Federal budget has been significantly reduced, and public investment seems remote, we must look at what corporate involvement in the PV has done toward sustaining the industry.

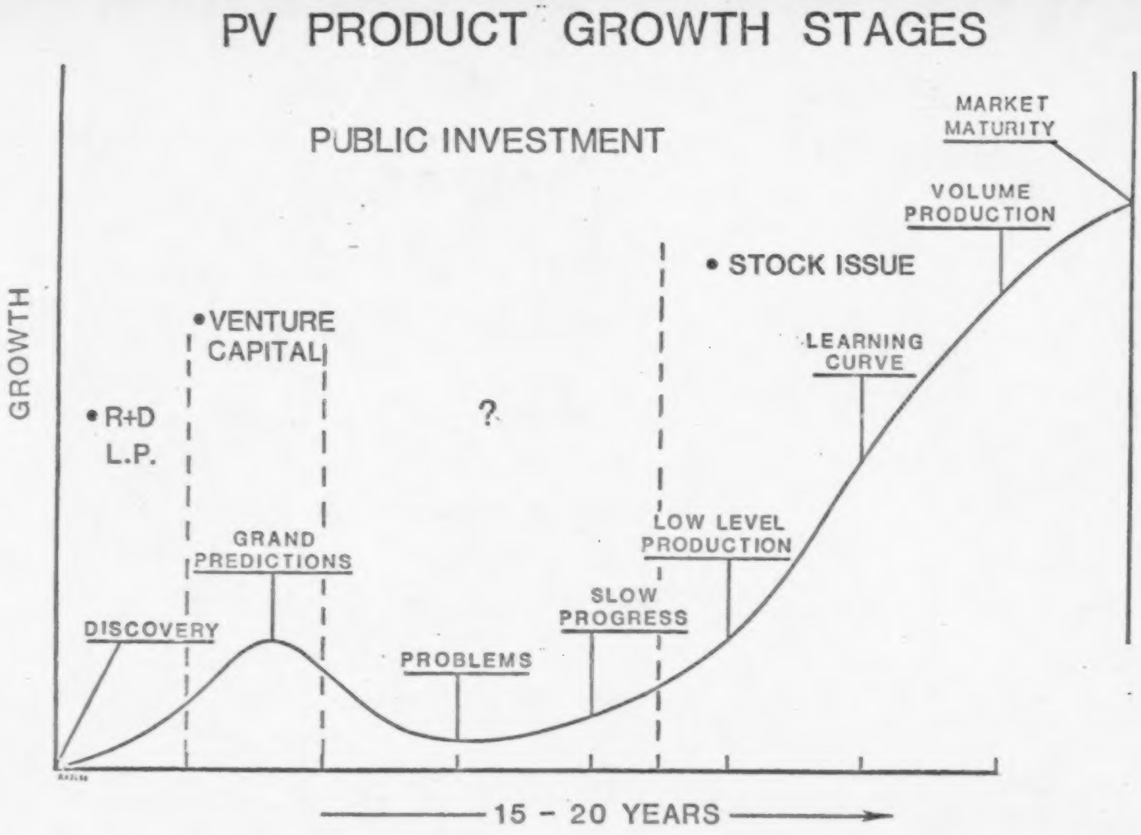

PV PRODUCT GROWTH STAGES
PUBLIC INVESTMENT
MARKET MATURITY
VOLUME PRODUCTION
• STOCK ISSUE
GROWTH
• VENTURE CAPITAL
LEARNING CURVE
• R+D L.P.
?
LOW LEVEL PRODUCTION
GRAND PREDICTIONS
SLOW PROGRESS
DISCOVERY
PROBLEMS
15 - 20 YEARS

FIGURE 5.

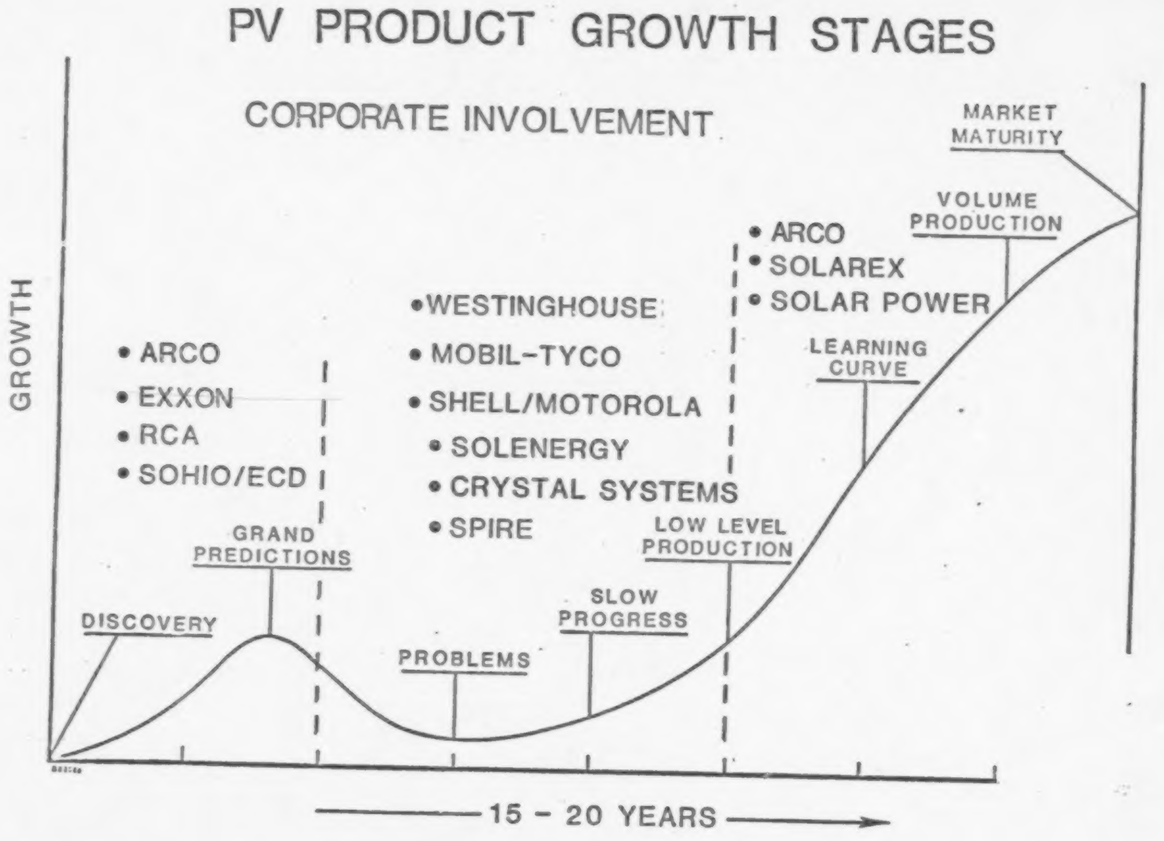

PV PRODUCT GROWTH STAGES
CORPORATE INVOLVEMENT
GROWTH
• ARCO
• EXXON
• RCA
• SOHIO/ECD
•WESTINGHOUSE
• MOBIL-TYCO
• SHELL/MOTOROLA
• SOLENERGY
• CRYSTAL SYSTEMS
• SPIRE
• ARCO
• SOLAREX
• SOLAR POWER
MARKET MATURITY
VOLUME PRODUCTION
LEARNING CURVE
LOW LEVEL PRODUCTION
SLOW PROGRESS
PROBLEMS
GRAND PREDICTIONS
DISCOVERY
15 - 20 YEARS

FIGURE 6.

## 7. CORPORATE INVOLVEMENT

Representative major organizations participating in the PV industry are shown on the PV Product Growth Stage Curve of Figure 6. In viewing corporate involvement, it is necessary to perceive the "industry" as being divided into two major areas. These areas are first, those organizations interested in large Volume Production characterized by impacting national energy requirements. This group of corporations generally pursues the breakthrough path for achieving Market Maturity, having written off existing technology as being too expensive. Secondly, there are those companies trying to make a business of PV in today's markets. These companies are generally in the Slow Progress and Low-Level production regions of the growth curve.

Currently, at least eight major oil companies have invested and are playing a major role in photovoltaics, with both long term research and Learning Curve production. The federal government has been important in identifying the technology options upon which both today's industry and investment are based. In many cases, initial entry into photovoltaics by the oil industry came from acquisition of smaller entries whose technology was nurtured by the federal government. In some cases, the federal government provided technology evaluations, in others, a market for an early product. With the entry of major energy corporations into photovoltaics, much of the initial role of government has been taken over. These corporations feel confident that they can now carry the technology forward, especially with single-crystal silicon.

In addition to the major PV industry entities, a number of smaller activities have been encouraged by federal support. These range from the development of processing equipment such as crystal pullers and ion implanters to silicon material processing sequences—all important to advance the present technology. The position of these small and medium size corporations is one of considerably less confidence than the oil-based industry. There is a real danger that this valuable infrastructure will not survive proposed government cutbacks.

Because of its modular nature which is conducive to small-scale utilization, PV offers near-term commercialization both domestically and internationally. An aggressive, multi-corporation approach involving today's industry would be the best strategy to capture this market.

It is interesting to note that the Japanese industry, which appears to be evolving rapidly, is dominated by semiconductor manufacturers. The Japanese semiconductor manufacturers are drawing parallels to their successful entrance into the semiconductor industry when U.S. manufacturers dropped their guard during the 1974 recession. Japanese investment in 1982, especially by government, is comparable to ours. PV has been targeted by the Japanese as a major high technology product in their export industry.

Finally, there is concern that the oil industry may lose interest in photovoltaics because of the present oil glut. Should the oil industry withdraw from photovoltaics, the industry would collapse and the federal government's investment go unutilized.

## 8. SPECIFIC R&D FUNDING RECOMMENDATIONS

Although a substantially higher budget of $90M would be much more effective, specific R&D funding recommendations, based upon a $54M PV budget, are presented in Table 1. The direction of funds into these particular areas would provide the opportunity for high efficiency thin-film breakthroughs for long term national energy impact through Advanced Research and Development. Also, Technology Development would address higher efficiency and lower cost silicon, important to help today's industry move out of the Problems trough up the production Learning Curve.

## 9. SUMMARY

In summary, the point that has been made is that the current PV industry is fragile and could lose ground on an international front, which would weaken prospects for national energy contributions. The investment made by the Federal government to bring the industry to its present level is in jeopardy. Government involvement is necessary to insure health and continuing growth. This is especially true in the trough of Problems and Slow Progress of the PV Growth Stage Curve in which much of today's most promising approaches for low cost PV production find themselves.

Table 1
PHOTOVOLTAICS R&D PRIORITIES
(Based upon $54M budget)

| | |
|---|---|
| Advanced Research and Development and Polycrystalline | |
| SINGLE CRYSTAL THIN FILMS | $10M |
| Silicon | |
| GaAs | |
| CdS/CuInSe$_2$, CdTe, others | |
| ADVANCED HIGH EFFICIENCY CONCEPTS | $6M |
| Single-Crystal Silicon | |
| Multi-Junction Thin Film Cells | |
| AMORPHOUS Si | $4M |
| Single-junction | |
| Multi-junction | |
| IN-HOUSE RESEARCH AND DEVELOPMENT | $ 5M |
| | $25M |
| Technology Development | |
| HIGH-PURITY/LOW-COST SILICON MATERIAL | $5M |
| Fluidized Bed Reactor | |
| Advanced Siemens | |
| ADVANCED SILICON SHEET (RIBBON TECHNIQUES) | $4M |
| WEB, ESP, LASS, EFG | |
| HIGH EFFICIENCY SILICON PROCESSING | $5M |
| FLAT PLATE MODULE DURABILITY ( 20 YEAR LIFE) | $3M |
| Encapsulation Materials | |
| Failure Mechanisms | |
| Accelerated Life Testing | |
| CONCENTRATOR COLLECTORS | $5M |
| High Efficiency Concentrator Cells | |
| Optics, High Temperature Encapsulation, Receivers | |
| BALANCE OF SYSTEMS | $1M |
| DEMONSTRATION PROJECTS | 0M |
| | $23M |
| System Engineering and Standards | |
| Performance Testing and Data Collection | $2M |
| Standards Development | $2M |
| Data Acquisition | $2M |
| | $6M |

## STATEMENT OF

T. W. FRASER RUSSELL, DIRECTOR
INSTITUTE OF ENERGY CONVERSION
UNIVERSITY OF DELAWARE

### INTRODUCTORY REMARKS

Good afternoon. I am most appreciative of this opportunity to address this important committee of the House of Representatives and bring to your deliberations the experience of one of the major university-based photovoltaic research and development activities in the USA. My name is T. W. Fraser Russell. I am the Allan P. Colburn Professor of Chemical Engineering and the Director of the Institute of Energy Conversion at the University of Delaware.

The Institute of Energy Conversion is a research laboratory devoted to the development of thin-film photovoltaic cells. We have just this month moved into a new 40,000 square foot laboratory specially designed to carry out this research. The Institute has a staff of approximately 20 full-time professionals and 25 technical support staff. This number is augmented by faculty, graduate and undergraduate students from various departments of the University, visiting scientists and post-doctoral students. Our research is supported with 1.3 million dollars of federal funds administered by DOE/SERI and approximately 0.5 million dollars of funds from industrial concerns. Federal government funds administered through DOE and SERI are used in our basic research programs for design, synthesis, and analysis of electronic materials, photovoltaic device design and analysis, and device development. At the present time, we are working with the following thin-film solar cell systems:

- $Cu_2S/Cd_{1-x}Zn_xS$
- $Zn_3P_2$
- Amorphous silicon
- $CuInSe_2/Cd_{1-x}Zn_xS$

Industrial funds are used for a fundamental engineering research effort which we have entitled photovoltaic unit operations. This fundamental engineering research effort is necessary because the information needed for the commercial-scale design of photovoltaic cell manufacturing facilities cannot be obtained from bench-scale laboratory experiments. In carrying out our research and education efforts over the past decade, we have produced 40 professionals, now working in the growing photovoltaic industry, who have received all or at least part of their education and experience in photovoltaics at the University of Delaware.

## INTRODUCTION

In 1978 the Congress of the United States committed the nation to an aggressive research,development and demonstration program for solar cells when it passed the Solar Photovoltaic Energy Research, Development and Demonstration Act of 1978 (P.L. 95-950, November 4, 1978). This legislation mandated a ten-year, 1.5 billion dollar program with the primary objective of developing photovoltaic energy systems capable of supplying a significant portion of the national's electrical energy needs.

Congress made a wise decision in 1978 and those of us who try to meet society's needs through fundamental scientific and engineering research have set-up the laboratories, purchased equipment and engaged personnel to meet the goals defined by the Act.

The University of Delaware committed itself to photovoltaic research in 1972. It made a decision, at that time, to carry out research on thin-film low-cost solar cells. We did so because we felt that thin-film cells would provide for "the production of electricity from photovoltaic systems cost competitive with utility-generated electricity from conventional sources". It is necessary to recognize that conventional sources such as coal and oil are, in fact, solar energy which has been stored for us in a particularly convenient form. To use the sun directly to produce inexpensive electricity, very large areas of cells are required. To meet the Department of Energy's projected demand of 1 Quad of photovoltaic electricity in the U.S.A. by the year 2000, for instance, will require 620 square miles or 1600 square kilometers of 10% efficient cells. Today's embryonic photovoltaic industry must mature from a single crystal silicon cell, high-cost manufacturing operation to a mature thin-film cell low-cost manufacturing operation using a variety of different material systems. The thin-film research effort to date, now beginning to attract private funding, has been adversley impacted by uncertain, and in recent years, declining federal funds and has not been sufficient to meet the major goals that Congress set for our nation in passing the Solar Photovoltaic Energy Research, Development and Demonstration Act.

We must implement Congress's plan. It is an essential part of a rational energy policy for the United States. We cannot keep drawing on our bank account of stored solar energy without someday paying a very great penalty. Balancing our energy budget is as essential as balancing our national fiscal budget. We have enough energy from the sun; we need the research and capital investment to collect it efficiently.

## LOW-COST PHOTOVOLTAIC GENERATION OF ELECTRICAL POWER

Photovoltaic electric power generation facilities do not use stored solar energy in forms of coal or oil as do conventional plants, they are designed to use energy from the sun directly. The capital costs of such a facility are most conveniently represented by the following catagories

| | |
|---|---|
| Module Costs | $0.3 - 0.5 |
| Array Costs | $0.5 - 0.6 |
| Power Processing Costs | $0.1 - 0.2 |
| Total Capital Costs | $0.9 - 1.3 |

The figures are capital costs in $/watt for a typical thin-film photovoltaic power generation plant. The ranges represent an estimate of the degree of uncertainty in projecting present technology to what can be achieved with an effective research program. At these capital investments, electricity can be produced at a cost to the consumer of about 5 - 15¢/kW hr. depending upon how one carrys out the detailed economics.

To carry out the required research effort, money and people with the appropriate education are required. An integrated research plan must be developed which combines fundamental studies of new and existing electronic material, creative device designs and imaginative process engineering to assure that low-cost manufacturing can be achieved. Unless there is a continuous interplay among these different phases of research and development there can be no assurance that laboratory experimentation will be adapted into commercial-scale production technology. We must be able to produce millions of square meters of cells cheaply.

We need research into a number of material systems. In the last decade, 20 different systems have received some research effort. At the present time, the number of thin-film material systems under active development is more limited.

(1) Amorphous Silicon. Research has been supported by DOE/SERI, RCA, Energy Conversion Devices (ECD) and Chronar. There are two methods of making the film and cell efficiencies of 10% have recently (7/23/82) been announced. An intensive effort to develop commercial-scale production facilities is being carried out in Japan, building upon fundamental research from the U.S.

(2) $Cu_2S/(CdZn)S$. Research has been supported by DOE/SERI, Shell through their subsidiary SES, Chevron and Photon Power. There is one significant research effort in Europe. There are two methods of producing the cells, one is now in small-scale commercial production and the other is now an area of active production scale research. Cell efficiencies of just over 10% have been achieved and recent research into cell stability has produced promising results. A method of continuously depositing the active semi-conductor layers on a moving substrate has been developed which yields cells of efficiency within 2% of those made in the laboratory.

(3) $CuInSe_2/(CdZn)S$. Research has been supported by DOE/SERI and cell efficiencies of 10% have been achieved. This material system appears to be stable but supply and costs of indium may restrict its use for large-scale commercial production of electricity. Research into exploration and recovery of indium may help resolve the supply problem.

(4) CdTe/CdS. Research has been supported by DOE/SERI, Ametek and Kodak. Two deposition processes appear promising and efficiencies of laboratory scale cells are approaching 10%. Research into production technology is claimed to be underway.

(5) GaAs, InP, CdSe and $Zn_3P_2$. Support for research with these promising materials has come mainly from federal sources. Cell efficiencies have been achieved in the 4 to 7% range.

Over the past decade, federal funding for research into these thin-film systems has been on the order of 100 million dollars. Industrial funding is estimated to have been on the order of 20 to 30 million dollars. Although this is far less than orginally mandated by Congress, some considerable progress has been made in the technology.

Efficiency. In 1972 one material system, $Cu_2S$/CdS, had achieved reproducible efficiency of about 5%. Now four systems, $CuInSe_2$/(CdZn)S, $Cu_2S$/(CdZn)S CdTe and amorphous silicon have reached the 10% range.

A number of other new materials have been developed and $Zn_3P_2$, $CuInS_2$, GaAs and CdSe are in the 5% range.

Stability. Laboratory demonstration of very promising stability has been shown for $CuInSe_2$ and defect-free $Cu_2S$/CdS. Stability problems with amorphous silicon are being actively researched.

Materials Preparation. Many large-area techniques have been shown to produce good photovoltaic semiconductor films. These include physical vapor deposition, chemical vapor deposition, sputtering, plasma deposition, pyrolitic spraying and electrodeposition. Continuous deposition of CdS on a moving substrate has been shown to yield large areas of material from which high-efficiency $Cu_2S$/CdS cells can be made.

Basic Research. Heterojunction theory has been advanced and a good understanding of thin-film cells developed.

Commercial Development. At least three commercial pilot plants have been built or are planned and integrated module production has been demonstrated.

It is essential to maintain the momentun of the ongoing development of established material systems if America is to avoid relinquishing its present leading position in thin-film solar cells. However, prudence also dictates maintaining a small but viable effort to identify and develop new materials which could form the basis of the next generation of cells. Research priorities are listed under these two categories, and a third category which we feel is essential if large areas of cells are to be produced.

## A. Established Materials

- Fundamental studies and technology development for large-area thin-film photovoltaic semiconductors. Generic problem areas include uniformity, reproducibility and defects.

This is a field of study which has not yet matured and is essential to the success of thin-film large area devices in general. It is the direct analogue of the massive federal and industrial development of single-crystal semiconductor technology.

- Improved understanding, control and optimization of wide band gap n-type semiconductors.

The thin-film cells now well advanced are heterojunctions based on strongly absorbing p-type semiconductors, much more needs to be known about making and controlling the wide gap n-type window material, e.g. (CdZn)S, ZnSe.

- Continued device development and optimization of electronic and optical characteristics, e.g. built-in fields, anti-reflection coatings and light-trapping. Development of engineering features, e.g. gridding, interconnects etc.

Only first order device design and optimization has been carried out to date.

- Tandem cells and other novel high-efficiency thin-film structures.

There will always be benefits to improving efficiency and large-area thin-film tandem cells are just one possible route to higher efficiency.

### B. New and Emerging Materials

- Fundamental studies of material production and basic optical and electronic properties.

There should be universal acceptance of the need to continually expand the basic science underpinning an existing or emerging technology. Without a resevoir of new materials the technology would stagnate.

### C. Photovoltaic Unit Operations

Our experience at IEC has demonstrated the catalytic effect of federal support of basic research and development. We are now attracting commercial support of about half a million dollars/year to develop production technology as a consequence of the federally supported basic programs.

Some of this industrial funding has been devoted to our photovoltaic unit operations program. Unit operations research in photovoltaics is required because the information needed to make millions of square meters of solar cells per year cannot be obtained from laboratory scale experimentation. We need to do fundamental engineering research to solve the commercial scale production problem effectively.

# STATEMENT OF DR. JOHN F. SCHAEFER, HEAD, PHOTOVOLTAIC DIVISION NEW MEXICO SOLAR ENERGY INSTITUTE, JULY 28, 1982

I am pleased to submit a statement on behalf of the New Mexico Solar Energy Institute in support of the National Photovoltaic Program. I am currently head of the Photovoltaic Division of the New Mexico Solar Energy Institute (NMSEI) at the New Mexico State University in Las Cruces, New Mexico. I am also project director of the Southwest Residential Experiment Station, established in 1980 as part of the Department of Energy's National Photovoltaic Program (NPP). Prior to coming to NMSEI, I was in the Air Force for 21 years, working entirely in research and development.

In the following, I will argue for federal support of a balanced research program: some basic, some applied, and some developmental. Certain that others more qualified than I will argue for a strong basic research effort, the thrust of my statement is that support of developmental research is vital if the United States wishes to push photovoltaics as an alternate energy form ahead of the pace that natural market forces would allow. I submit that the United States should do so.

I believe that terrestrial photovoltaic (PV) systems will eventually become cost-effective relative to other sources of energy even in the absence of federal support, providing a substantial fraction of both this nation's and the world's energy needs. Federal support is important to hasten the time when all of us can consider the use of PV cells on our rooftops to provide electrical energy from sunlight. I believe it is in our national interest to quickly reduce this country's dependence on imports of fossil fuels and on use of our own nonrenewable resources. It is also in our national interest to support our industry, heretofore the undisputed leader in PV technology. We must consider the massive support the foreign competition receives from their governments. I do not believe that our industry has lost its lead, nor do I believe it inevitable that, without federal support, it will, but I do believe that the risk is enormous and consequences of foreign dominance are grave. Much has been said and written about Japanese penetration of our automobile market. Imagine the situation 20 years from now when automobiles are electrically powered. Will we all have a Toyota or Datsun in our garage, and a Hitachi or Sanyo PV array on our roof that supplies the energy for those vehicles?

It is also in our national interest to have a federally funded PV effort that can test PV systems under controlled conditions and ensure that the systems offered to you and to me are safe and reliable. PV projects under the NPP have carried out and can carry out vital experiments that neither the PV nor the electric utility industry can afford to do right now.

## BALANCED PROGRAM

I believe that, for a relatively modest investment, this nation's government can ensure that these aspects of our national interests are protected and can hasten the time when PV energy systems will meet a substantial portion of our energy needs. That investment should be substantially along present lines: a large effort in basic research involving materials and materials processes, and at least modest effort involving the fielding of working PV applications system with a feedback of results to manufacturers, integraters, and users. I am essentially a layman with respect to both the chemistry and the physics of PV materials and the mechanization of production lines. I know only from seeing and using the end products of today's manufacturing technology that today's product is too expensive to make a significant reduction in aggregate nonrenewable energy consumption. Other witnesses are far more adequately able to suggest specific direction of effort in the basic research and development areas.

## SYSTEMS-LEVEL RESEARCH

As an evaluator of the end product, however, I feel relatively comfortable in suggesting that existing, and perhaps a limited number of new, field test, evaluation, and demonstration efforts are or will be vitally important to the successful early implementation of significant numbers of PV energy systems and more than worth the funds invested. The argument can best be made if some of the activities and results of the Southwest Residential Experiment Station (SW RES) and the two intermediate-sized projects (PRDA-38) with which we have been involved at NMSEI, all funded under the NPP, are cited.

The SW RES, on the New Mexico State University campus in Las Cruces, is part of the Residential Applications Sector of the NPP. We were established in 1980 to field, test, and evaluate prototype residential PV systems. We currently have eight prototype systems up and running. They are based on full-sized southwestern residence designs. Each is physically just enough of the residence that the PV system exists and operates as though it were actually on the residence. It replicates the residential system mechanically, electrically, and thermally. We are also monitoring the energy usage of five Las Cruces families and a residential substation feeder to learn in detail how people use their energy throughout the day. We will shortly be monitoring two lived-in PV residences, one in Santa Fe, New Mexico, and the other in Yuma, Arizona.

Our purpose in erecting and testing these prototype PV systems is to learn and promulgate the best ways to do it and, simultaneously, the ways not to do it. It is much like an agricultural experiment station--to winnow the good from the bad. I consider that we are doing developmental research that significantly reduces the technical risk of fielding large numbers of systems. We are performing a function that is a vital part of the basic-applied-developmental research loop: we feed back information to both the basic and the applied researchers so that they may respond to needs revealed by system testing.

From experience and history, I know that basic researchers cannot anticipate all factors that make products workable. The function of a facility such as the SW RES or the PRDA projects is to unearth those factors and close the research loop before unworkable systems are unleashed on the public. With respect to the PV systems, I have no doubt that eventually the forces of the marketplace would perform that function, given time. Again, I submit that the issues are so critical to the energy welfare (and, eventually, total welfare) of the nation that we should not wait for those natural forces.

## LESSONS LEARNED

In large measure, there have been no major surprises from operation of the SW RES. The concept of a utility-interactive, roof-mounted PV system has proven well founded and technologically valid. There are clearly no major impediments to widespread adoption of such systems save the current economic (first-cost) issues. To so generalize is far from equivalent to concluding that SW RES establishment and operation has been merely a proof-of-concept effort. The SW RES participants, its sponsors, and industry have learned a great deal and, beyond any doubt, will learn more, particularly if new systems are fielded. Several phenomena have been discovered that are not yet totally understood (e.g., array operating temperatures, piggyback cooling schemes, multi-inverter run-on upon loss of utility); it is vital that these and others to emerge be fully understood. Attached as an appendix is an extract of the "Lessons Learned" summary of our interim report to the PV community. It lists and discusses many items, ranging in subject matter from good and bad ways to wire arrays on roofs to shipping costs to fairly technical issues about inverters. These findings were not totally obvious to us or to the PV industry teams that designed and implemented our systems before set up or operation of the systems.

Important lessons have also been learned from the existing field tests that support larger applications such as central power stations. NMSEI is involved in two of these; we are providing operation and maintenance information to the PV community and, equally importantly, to the utilities. This is an important area of great concern to utilities who are contemplating investment. Each of the two utilities with whom we are working has successfully performed operational maintenance for more than one year. Operations, maintenance, reliability, and repairability figures were originally estimated during life-cycle cost analyses for system design; the two systems are now providing actual data. We are building the data base for private industry's investment decisions. Information on distribution system interface, system availability, capacity factor, and peaking or base load replacement can be derived with continued operation. Hard data on all these factors are required before industry will commit significant dollars to PV energy systems. Our two systems and others over the nation have shown feasibility, have spawned private investment, have proven that nonspecialists can erect large PV arrays, and are providing hard data that will influence implementation. The government has a large investment in these systems; for a relatively small additional amount, the fruits of the original investment can be harvested.

## VALUE OF LESSONS LEARNED

I submit that knowledge of many of these items will save grief, wasted time, and perhaps lives for the PV industry and building trades innovators and will speed national acceptance of residential PV systems. Implementation of successful, acceptable systems will come earlier as a result. I will leave judgment of the question "How soon would the PV industry on its own have promulgated these findings?" up to the subcommittee members.

## DISCUSSION OF ONE "LESSON"

I wish to stress the issues involved in at least one of the findings at the SW RES. Each U.S. electrical utility that I know of has stipulated, in its small power producer interconnection agreement to purchase energy as stimulated by PURPA (the Public Utility Regulatory Policies Act of 1978), that the producer's generating equipment disconnect itself from the utility's lines if the utility goes down. On the surface, that is a reasonable requirement motivated by the clear need to protect the utility crew as it attempts to restore service. But I postulate that there are not only possible but probable scenarios, as small co-generators proliferate, in which each individual generator in an aggregate of them, sensing only the voltage amplitude and frequency on the distribution network, cannot determine whether the serving utility is or is not present, hence neither it nor the aggregate of them on the network will disconnect. The required conditions for this scenario to unfold are, roughly, that aggregate production on a discrete portion of the network be equal to aggregate load (consumption). In such a case, the utility feeder serving the discrete portion will be providing no energy and no current--hence if the line is broken, there is no sensible change in conditions within that portion of the distribution system. It would represent a stable condition for as long as the distributed production/load relationship held.

If order to lend credibility to our postulated scenario and its possible ramifications, we conducted a controlled experiment at the SW RES. We have the ability to control electrical load within the confines of the station. On November 24 of last year, a sunny day, we initiated a series of tests in which, with various inverters and loads tied to our site power distribution network, we simulated (with the master circuit breaker to our utility feed from the El Paso Electric Company) a utility outage. Indeed we found that with load equal to total instantaneous production, as few as two inverters would continue to operate for finite periods (they were manually shut down after 10 seconds of operation).

Quite naturally, various utilities were extremely interested in these results, which were immediately made available both to the NPP and, through our regional consulting committee, to most major southwestern utilities. Several have requested additional work in this area. I am quite sure that as a consequence of this work, many utilities are revising their maintenance procedures so as to no longer have blind faith that the transmission line downstream of the break is dead.

The foregoing is but an example of the kinds of systems-level tests that, presently, only the two residential experiment stations and similar facilities can do. No single utility or group of them has a similar facility. One utility, Southern California Edison, has been experimenting with a single PV-fed inverter for the last three years. I presume its research and planning group would have had many more on-line to investigate the kinds of phenomenon described above had the funds been available. We at the NMSEI are presently making plans to solicit support from the electrical utility industry in the event of disappearance of federal funds. Indeed we shall solicit funds to augment the current DOE-funded efforts regardless of the way we perceive the federal-funding winds to blow.

I submit that the activities at the SW RES and other systems test and evaluation facilities are extremely important functions lying outside a strict definition of "basic" research that will heavily influence the time at which PV energy systems begin to make a measurable contribution to our nation's--and the world's--energy supply.

## LEVEL OF FUNDING

I have not speculated what I think the level of federal support should be. I cannot provide an absolute figure for I am not adequately familiar with the total DOE program. I have been notified that at the administration's proposed FY 1983 level of $27 million, all facilities such as and including the SW RES will be shut down, so it is easy for me to say that $27 million is not enough. The FY 1980-81 level, with proper balance, would give me confidence that a serious effort was being made to ensure early--and successful--implementation.

## PUBLIC ACCEPTANCE

As a final note, I point out that both public and local and state government perception of the utility, reliability, maintainability, and workability of PV systems will play an enormous role in determining the "when" of acceptance and widespread implementation. If the RESs and similar facilities were to serve no other purpose than to guarantee public acceptance of such systems, I submit it would be worth the investment to our future.

Thank you.

## APPENDIX

### LESSONS LEARNED SUMMARY

In order to give the subcommittee a grasp of some of the good and bad that the Southwest Residential Experiment Station effort has identified, an extract of the "Lessons Learned" section of our Interim Report to the PV community is replicated almost verbatim below. (References are omitted.)

°Array temperatures - Array mounting methods and module design both heavily impact array operating temperature and, hence, array efficiency. Both factors are believed to require substantial further work.

°Supplemental cooling - One such scheme has potential for being cost-effective, one apparently does not. SW RES staff will quantify these two schemes later, but it is doubtful that findings will totally answer all issues.

°Shipping costs - The Applied Solar Energy Corporation modules on the TriSolarCorp (TSC) Prototype incorporated 4-inch-deep junction boxes on the rear substrate. Highly convenient for the electrician, these boxes severely impacted shipping costs. Their presence dictated that each pair of back-to-back modules be separated by 4 inches of packing material (rigid foam); thus, volumetrically, each shipping container contained at best about 85 percent foam and 15 percent module. Shipping costs, Los Angeles to Las Cruces, were apparently more than $3,000, roughly 60 cents per installed watt (a dedicated, air-ride carrier was used). The Motorola modules on the Total Environmental Action (TEA) Prototype, about 1-inch deep, were efficiently packed 10 to a carton (TEA shipping was $213, Phoenix to Las Cruces). Clearly the mass-marketed module of the future will either have a slim junction box or the latter will be attached in the field.

°Fauna under standoff arrays - On one occasion an owl was found trapped under the Applied Research and Technology of Utah (ARTU) Prototype standoff array (a 4-Pak had to be lifted to allow the bird to escape). It was suspected that the owl entered at the roof peak and could not exit at the array foot because of a narrower gap. Steps should be taken to prevent such occurrences.

°Reflective roofing aggregate - It has been confirmed that white roofing aggregate can enhance array performance, but not greatly. A generalized life-cycle cost-effectiveness study is planned.

°Building codes - Effort is under way to "change the code" to facilitate residential roof-mount PV system implementations. SW RES staff wonder if the codes will change rapidly enough. On one inspection of the General Electric (GE) Prototype System, the assigned state construction inspector told us that he could not allow such a system to be constructed out in the community (the

FCC® ribbon cable is currently approved only in installations under carpet tile). After the eight Critical Design Reviews were completed, we promulgated, only partly in jest, the "National Electric Code (NEC) Lemma: The least lower bound on the number of possible interpretations of the NEC is equal to the number of interpreters."

°Wiring costs - As a corollary to the above, this example is offered. Prior to the Critical Design Review, one contractor chose to interpret the NEC very rigorously. The contractor's interpretation was that use of coaxial cable (normally used in radio frequency applications) with appropriate connectors was the most attractive and acceptable mechanism to accomplish intra-array wiring. Parts cost alone would have exceeded $3,000. After redirection to search for a less-costly approach, cost was reduced to about $250.

°Solarex cap strips/battens - It was learned that the 1½-inch wide plastic battens on the Solarex standoff array cannot be reused. It was further learned that the color (light blue) changed markedly in less than six months of exposure to the New Mexico sun. If array maintenance involving module lifting or removal is necessary, the result will be aesthetically very displeasing unless either all battens are replaced or unused replacement battens have been allowed to similarly age. A redesigned batten with better weathering characteristics may allow reuse.

°Learning curves - There was clear manifestation of a substantially sloped learning curve associated with all array installations. For example, the first few modules on the BDM Corporation system averaged 12 minutes installation time; the last, about 4½ minutes.

°Diagnostic wiring - At NMSEI request, the GE Prototype was fitted with special diagnostic wiring. A special #18 gauge wire was run from each row of shingles to an interior junction box. SW RES erred in this installation. Because of the extensive paralleling in the GE array, the resistance associated with these varying-length wires precludes accurate measurement of block current and, therefore, realistic I-V curves. Either heavier wiring (preferred) or equilength wires (the latter would still not allow taking accurate data unless wire resistance were known) should have been required; either would allow meaningful comparison, row to row. It is, of course, not yet clear whether such special diagnostic wiring will or should be incorporated in a mass implementation of residential PV systems. If it is, such factors as discussed here should be considered.

°Wind direction and array temperature - An exceptionally strong correlation between wind direction and array temperature was found in the TSC and ARTU implementations. In an area with a strong annual prevalent wind pattern, it may be well worthwhile to attempt to capitalize on this phenomenon.

- Wind during installation - The TSC array was installed at the beginning of the Las Cruces windy season. Array installation was not severely slowed (about 8 man-hours were estimated as lost; total installation labor was 109 hours), but only because of the bravado of the installation team (individuals were management principals in the effort) and the acquiescence and enthusiasm of all involved parties (it was the first SW RES array). If forecasts of 25-square-foot modules being the most cost-effective are correct, then it can be speculated that in some areas with high wind seasons, installation will be avoided during such seasons.

- Owner's manuals - An owner's manual was not called for as a specific deliverable in the eight Prototype System procurements. More important, not a single one of the eight vendors proposed to furnish an owner's manual. When prompted, most of the eight agreed that it would be appropriate. To date, however, only three have provided acceptable documents. SW RES staff wonder, with some trepidation, how easy it will be for the future layman PV-home owner to know whether or not his system is working at all, much less properly. To the best of our knowledge, Brand X did not provide a complete drawing set or maintenance manual for its inverter to any of its SW RES customers, and a similar but perhaps more understandable situation holds for the first-off-the-production-line Brand Y inverter.

- Post-installation cleaning - Following a dust storm shortly after the TEA array installation, finger and palm prints all over the TEA array were noticed from 50-foot distances. A subsequent washing eliminated the marks. In areas such as Las Cruces, it is clear that a post-installation cleaning will be a mandatory part of the deliverable.

- Energy loss in isolation transformers - Based on performance of the two Gemini-associated isolation transformers at the SW RES (which apparently lose on the order of 1 kilowatt hour per day), it is concluded that either their use not be made mandatory or that investment in more efficient units will probably be life-cycle justified.

- Inverter/array rating game - Experience with the ARCO Solar System (7.4- kilowatt-peak array, 8-kilowatt Brand X inverter) suggests that an x-kilowatt-rated inverter must be able to tolerate the vagaries of terrestrial PV arrays. Specifically, if tied to an array rated at x-kilowatt under one sun, the inverter must be able to handle on the order of 1.4 suns . . . either by allowing 1.4x power surges or by restricting same through operating point changes (note that the 6.7-kilowatt peak GE array tied to the 6-kVA Brand Z inverter caused no problems).

- Inverter protective circuitry - SW RES staff strongly believe that all inverters should incorporate relatively sophisticated protective circuitry. Specifically, they should incorporate voltage and frequency windows. Nonetheless, no matter how sophisticated each single inverter's circuitry is (if it senses only the nominally 60-hertz line), there are potential scenarios in which no single inverter in an aggregate of them will be able to discern presence of the utility. Thus, while utilities can demand that inverters shut down in the utility's absence, utility linesmen should not depend on this happening.

°Roof weatherseal - The ARTU array cooling scheme as implemented at the SW RES will probably not see widespread adoption. If this is not the case, greater care must be exercised to preclude construction debris from collecting in the air distribution duct.

°BOS component ratings - Both the NMSEI staff and two of our subcontractors forgot some of the peculiarities associated with dc versus ac power handling devices. One subcontractor installed underrated (in voltage) fuseholders and fuses in the array summing/junction box. Following an inverter failure that left the array shorted, one of the fuses must have opened, but an arc apparently struck from fuse end to fuse end. It appears the arc did not extinguish until conducting components were eroded to a critical distance. Later, a second subcontractor arrived on site with underrated fuses in his summing/junction box; these were upgraded prior to installation.

°Intra-array wiring - Our limited observation of array installation activity yields these strong conclusions:

1. Modules should have bypass diodes installed as shipped from the factory.
2. Modules should have polarized, plug-in connections.

Our basis for these conclusions is best provided by a discussion of the contrast in labor hours reported by Solarex and TEA for wiring the corresponding SW RES prototype arrays. Solarex reported a wiring materials cost of $615 and 30 hours of labor. TEA reported $1,085 and 117 hours. We did not request a further breakdown of on-site versus off-site labor hours, but we did observe that the actual Solarex wiring effort on site was substantially less than 30 hours, whereas the 117 hours reported by TEA was almost entirely on site. The principal difference in these costs (which normalize to 21¢/watt and 66¢/watt, respectively, if labor is calculated at $15/hour) is attributable to the Solarex modules' integral bypass diodes and quick-connectors versus the requirement to remove two Motorola junction box covers, install diodes and connections, replace covers, and make intra-array connections. We believe this to be a significant balance-of-system cost driver.

°Array/inverter interface - Without trying to assess responsibility for the Solarex and TEA arrays/Brand Z inverter interface problem, it is clear to us that the term "operating voltage range" needs to be augmented, probably quantitatively and qualitatively, with additional information regarding allowed open-circuit (or "get-started-inverting") voltages. Additionally, the TEA array open-circuit voltage exceeded the upper limit (originally 260-volt, now 300-volt) on its Brand Z inverter voltage window. Conceivably a new-technology, low-fill-factor array might emerge, with an open-circuit voltage of twice the maximum power point voltage. We believe the ball is in the inverter manufacturers' court for a marketable device capable of large windows on both voltages.

°Array maintenance access - Most of our subcontractors' weakest performance aspect was associated with providing well-thought-out guidance and/or means for gaining physical access to arrays. As of report preparation, we still await a maintenance ladder design from one subcontractor.

°Inverter environments - It was not until July 1981 when we were working in the "garage" portion of the Westinghouse prototype system that we fully appreciated the significance of the operating temperature ranges of available inverters. That range is
Brand Z: 0°C ≤ temperature ≤ 40°C
Brand Y: -18°C ≤ temperature ≤ 43°C
Brand X: 0°C ≤ temperature ≤ 40°C
For the modified (with a 60-ampere fuse) Brand X in the ARCO system the high limit has been reduced to 32°C. For the desert Southwest, the upper limit must be increased. Ambient temperatures routinely exceed 40°C in many areas, and unconditioned spaces such as garages and equipment rooms can exceed 50°C. For equivalent reasons the lower limits of the Brand X and Brand Z must also be extended.

°Importance of realistic operating environment - As previously discussed, the great majority of Brand Z failures occur at low irradiance periods, either morning wake-up, evening shutdown, or during cloudy conditions. In hindsight it is easy to say the manufacturer should have cycled the dc power supply, which was probably used to qualify the production inverter, several thousands of times instead of several tens or hundreds of times to more fully check out the wake-up/shutdown circuitry. The point here is that a field test, with real solar irradiation on an array, revealed a deficiency that a relatively thorough laboratory-environment qualification test did not.

°Maximum power point tracking - We have mixed results, and only a tentative conclusion, with respect to maximum power trackers (MPTs) on residential-sized arrays. No Brand X MPT was evaluated due to early rumors of problems. Brand Z MPT performance was mixed--some good, some poor. The single on-site Brand Y MPT has, to date, been reliable in that it does bracket the array maximum power point, but its discrete voltage steps seem to be excessively large (we plan to quantify energy loss as a function of step size in the near future). Recent results from a number of simulations for different sections of the U.S. indicate that only rarely will the energy lost by a fixed-voltage array approach 3 percent (and 1 percent is a more typical figure) of that collectible by using a perfect MPT. We tentatively conclude that the gain in reliability and decrease in cost by using a simpler fixed-voltage control probably will justify foregoing that 1 percent to 3 percent loss of annual energy. When Brand Z changed its MPT to a pilot cell voltage control, they saved 24 integrated circuits and 4 power transistors. Further, as speculated earlier, use of a pilot cell probably reduces the loss to insignificance and, electrically, simply replaces the typical potentiometer voltage reference in fixed-voltage inverter logic with one PV cell and its wiring.

Mr. **Fuqua**. Thank you very much, Dr. Schaefer.

Dr. Russell, do you believe that the advanced research and development programs at SERI are pursuing a sufficient number of promising thin-film concepts, or are they pursuing too many?

Dr. **Russell**. I believe that the balance is about right as it exists now.

Mr. **Fuqua**. You are satisfied with the balance, then?

Dr. **Russell**. Yes.

Mr. **Fuqua**. Mr. Little, do you think that JPL should play the same role in the future of thin-film materials that it played in the past in flat-plate silicon?

Mr. **Little**. Once a thin-film material has been shown to be a stable, reasonably high efficiency, viable material, ready for module manufacture, then I believe JPL should work on the problems associated with that technology development.

Mr. **Fuqua**. Dr. Schaefer, how serious do you believe the foreign competition is, or is likely to become, in the next few years in the photovoltaics industry? Perhaps all of you would like to comment on that.

Dr. **Schaefer**. Sir, I have not been to Japan. I know only what I read and what I am told and what I hear. My impression is, and I have just spoken to Mr. Maycock, who used to run the DOE photovoltaic program, and he just made a 2-week trip there—my impression is that we ought to be running scared.

Mr. **Fuqua**. Dr. Russell?

Dr. **Russell**. I believe we have taken the wrong view toward the commercial-scale development and not done a good enough job at concentrating our efforts on the proper analysis and the fundamental engineering to move from the laboratory to the commercial scale. I think that the effort has not received the attention it should.

Amorphous silicon is an example. It was developed essentially at RCA, both with RCA monies and Federal monies. The Japanese acknowledge that the fundamental work was done there. There is no reason why an integrated program couldn't have got us into commercial-scale production with amorphous silicon. This Nation has in the past had some remarkable successes. We did this with penicillin at the beginning of the second world war. The cooperative effort amoung Government agencies, industrial concerns and universities developed penicillin manufacturing techniques, to the point where we were able to meet the D-day invasion needs. We seem to have forgotten that we are capable of doing that.

Mr. **Fuqua**. Mr. Little, how do you view the competition?

Mr. **Little**. I think the Japanese competition is serious. I think that the amorphous silicon has gotten a lot of visibility because they are doing a lot of it, but that is for watches and games, and so forth. I am more concerned about the single crystal effort which is predominantly what is called the sunshine project. The sunshine project's budgets next year, I believe, should be comparable to our own budget.

I think the Japanese have targeted photovoltaics as a major part of their high technology export business in the future. I think it shows up because not only there are government activities but because the technology rests in semiconductor industries, which are short-term thinkers in terms of return on investment. So they are going to get out there quickly and they are going to get out there with silicon, and I think they are a major threat.

Mr. FUQUA. Mr. Gregg?

Mr. GREGG. Thank you, Mr. Chairman.

Mr. Little, the quote that I see around is that it costs about $18 a watt for photovoltaic power. Is that correct?

Mr. LITTLE. I think modules are $8 and systems are probably $14.

Mr. GREGG. That works out to a form of energy that really is not competitive with anything that is presently in the marketplace, right?

Mr. LITTLE. For utilities?

Mr. GREGG. For utilities, for consumption in an urban society or a society which has ready access to production of electricity.

Mr. LITTLE. With the tax credits given now, both Federal and in the State of California, PV systems can be fielded for voided energy costs of 12 cents a kilowatt-hour. That is high, but it appears to be competitive, for instance, in San Diego. San Diego Gas and Electric is seriously looking at a PV utility system with those economics.

Mr. GREGG. So you think you can develop systems which are going to be able to compete in an urban society; is that what you are saying?

Mr. LITTLE. Eventually, yes.

Mr. GREGG. But in order to do this, you think you need a lot of Federal dollars, I take it, to generate the type of activity in the development of the processes, and in the development of the facilities?

Mr. LITTLE. I think we need Federal dollars to insure that there is a healthy industry so they can pick up and perform the role that the Federal Government is now performing, and that is principally in a near-term market, which is associated with remote power, and so forth, and helping solve problems which then bring the cost down from that stage.

Mr. GREGG. Are you talking about direct grants?

Mr. LITTLE. No, I am talking about competitive procurements with costsharing. I think the photovoltaic program has been predominantly that. It has been a very healthy program.

Mr. GREGG. If you take those sorts of dollars and put them into the photovoltaic program, what is the time frame that you see before you arrive at a competitive program that would not need Federal support?

Mr. LITTLE. If you take $90 million and put it in there for 5 years, you may solve 90 percent of the problems and reach a point where the industry has taken the whole thing over.

Mr. GREGG. But you don't see that occurring without the $90 million of seed money, so to say, from the Federal Government?

Mr. LITTLE. No; I do not. Certainly not in that time frame.

Mr. GREGG. Well, what is the argument that leads you to conclude that the Federal Government should initiate that sort of commitment to commercialization? Why shouldn't we let the marketplace settle the issue?

Mr. LITTLE. Because no one is profitable. Everybody is going out of business except the major oil industries, which are investing upon speculation, and I think there is a question as to how long they will have patience with photovoltaics, especially with the oil glut and the ability to make a great deal more profits in other ways.

Mr. GREGG. Well, how do you present your argument in the face of a $150 billion deficit that is creating interest rates which are generating a lack of profitability across the board to most of the economy?

Mr. LITTLE. I present my argument in terms of relative issues, relative to breeder reactors, relative to fusion programs, relative to nuclear programs, relative to space-based lasers, relative to inertial confinement fusion.

Mr. GREGG. I see. If the Federal Government is in those businesses, then they should be in photovoltaics.

Mr. LITTLE. It is a value judgment as to where resources are best allocated, and it is my judgment that they are best allocated in the photovoltaics program.

Mr. GREGG. Do you see a better potential for production of electricity in photovoltaics than, let's say, breeder reactors?

Mr. LITTLE. Frankly, I am not that close to breeder reactors, but try another one.

Mr. GREGG. Fusion.

Mr. LITTLE. Absolutely.

Mr. GREGG. I guess I would ask the rest of the panel, if you were to balance your program against fusion, do you feel the same way as Mr. Little?

Dr. RUSSELL. I think there is more potential for photovoltaics than there is with the fusion. This Nation has put $20 billion to $40 billion worth of research into nuclear, and we still outline moves into research. We have put less than $100 million into thin-film photovoltaic cell research. We have put $5 billion to $10 billion into synthetic fuels. We are not anywhere near this level of research funding. We have not even begun to find out what we can do with photovoltaics yet.

Mr. GREGG. Dr. Schaefer?

Dr. SCHAEFER. Sir, I do not know very much about fusion, but as I understand it, no fusion device or technology has broken even yet. We break even at the Southwest RES every day. We generate more energy there than we consume. PV works; I will say it again. Fusion may, but I am not qualified to say any more about fusion.

Mr. GREGG. So essentially you are saying that, in the battle for energy dollars, you are not asking for more dollars to be spent in R&D; you are asking for dollars to come out of the fusion program or some other form of nuclear program to be put into the PV progam. Is that correct? Can we get that on the record?

Dr. RUSSELL. That is my perception.

Dr. SCHAEFER. I was not necessarily asking that, sir. I think I remember $20 billion—I am sorry, I don't remember what the Clinch River budget was. I remember, when I saw it, I was aghast, knowing that the administration intended to no longer fund solar programs and intended to fund Clinch River at that level.

Mr. GREGG. It is $252 million, I think.

Is that your position, Dr. Russell?

Dr. RUSSELL. Yes. I think that the $252 million could be much better spent in photovoltaic research.

Mr. GREGG. Mr. Little?

Mr. LITTLE. Very definitely.

Mr. GREGG. Thank you.

Mr. FUQUA. Mr. Weber?

Mr. WEBER. No questions.

Mr. FUQUA. Mr. Nelson?

Mr. NELSON. Just a comment, Mr. Chairman.

I think a lot of people are going to have a different tune when the oil stops flowing out of the Persian Gulf to the free world, and we will suddenly have everybody scrambling to get R&D money back in for alternate energy sources.

Mr. FUQUA. Thank you very much.

We likewise would like to seek your permission to submit written questions to you, and if we have some, we will get those to you very shortly.

Thank you very much for being here this afternoon.

Our third panel will be Mr. Daniel Shine, Sanders Associates, from New Hampshire; Dr. Alvin F. Hildebrandt, director of the energy laboratory, University of Houston; and Dr. Merwin Brown, manager, research programs at Arizona Public Service Co. in Phoenix.

We will begin with you, Mr. Shine. As I mentioned to the others, we will make your prepared statements in their entirety part of the record. If you wish to summarize, we would be pleased.

## STATEMENTS OF DANIEL SHINE, SANDERS ASSOCIATES, NASHUA, N.H.; DR. ALVIN F. HILDEBRANDT, DIRECTOR, ENERGY LABORATORY, UNIVERSITY OF HOUSTON, HOUSTON, TEX.; AND DR. MERWIN L. BROWN, MANAGER, RESEARCH PROGRAMS, ARIZONA PUBLIC SERVICE CO., PHOENIX, ARIZ.

Mr. SHINE. Thank you, Mr. Chairman.

I thank you for the opportunity to provide testimony on an important subject. I am speaking from the point of view of a company which has been involved in solar research for 8 years.

My testimony will concern primarily parabolic dish technology; specifically, solar thermal electric parabolic dish technology.

For those of you who are unfamiliar with what this technology represents, I have submitted as part of my written statement a schematic representing a typical system.

Parabolic dish systems are one of several solar thermal concentrating technologies presently under development by industry and the Department of Energy. They typically involve a parabolic concentrator which focuses sunlight on a receiver. The receiver contains an operating fluid, which may be a liquid or a gas, circulating through it. This operating fluid may be piped to the base for some thermal application or may be piped into an engine generator at the focal point to generate electricity.

One of the features of this type of system is the fact that it represents a modular technology with a wide temperature output range. Parabolic dish systems are effective producers of thermal energy from 300° to 1,500° C. In a solar thermal electric mode, one module can produce up to 25 kilowatts of electricity; in the thermal mode it can produce up to 70 to 80 kilowatts of heat.

The Federal Government has spent a great deal of time, effort, and dollars in developing dish technology over the past 6 to 10 years. As I have outlined in my prepared statement, various components of the parabolic dish module have reached varying stages of development.

Relative to the concentrator, several contractors have developed systems and subsystems to the point that there are now concentrators being tested at various Government and private facilities. The concentrator itself tracks on two axes, elevation and azimuth.

The conventional dish system features a paraboloidal mirror, but there are various other technologies and systems being developed. The principal consideration is the ability of the mirror to reflect sunlight. The technical questions which remain to be answered are the bonding problems on the concentrator layers, the degradation of surface materials in the operating environment, and decreasing concentrator weight and cost while maintaining structural integrity.

As in the case of the concentrators, several different types of receiver have been developed and tested ranging in temperature from 700° F. to 2,600° F.

The receiver in the dish system absorbs concentrated solar radiation. The primary technological questions which must be answered are how high a temperature can be generated and what the weight and structure penalties are at the very high temperatures.

Several types of engine are also being developed in connection with the dish program. The technologies represented include Brayton or gas turbine technology, Rankine or, most typically, steam turbine technology, and Stirling engine technology, which is an external heat source engine.

The primary questions being researched involve high engine efficiency and reliability.

Another parabolic dish technology subsystem presently being researched is storage. Several different storage concepts are being examined. In the Rankine engine or the steam turbine type system, various oil and rock mixtures are being investigated. There are also ceramic technologies being developed to provide buffer storage in Brayton and Stirling engine systems for covering those periods when insufficient sunlight is available.

One of the features of the Stirling and Brayton systems being developed is the fact that they can be operated in a hybrid mode; that is, they can burn a conventional fossil fuel or a low-BTU biomass gas during those periods when there is no sunlight or when there are clouds or after dark, thus diminishing the storage requirement.

A final area being examined is in the area of controls; i.e., controlling both the dish and the engine. The foregoing describes the present status of dish technology. The primary question that I see that this committee is addressing is where do we go in the future.

I think the best way to address that is to go over where the Government has taken us to this point, more pointedly where the Department of Energy has brought us. In my opinion, the Department of Energy has proven to be a rather effective technology development broker. Component demonstration programs have been very successful to date. What remains to be conducted are systems evaluations.

The demonstration programs conducted to date have taken place primarily at Government-owned and operated facilities. These facilities are not the types of facilities that industry or a group of industries could support on a private-use basis. The facilities that I am referring to are those operated by the U.S. Army at the White Sands, New Mexico, Sandia Laboratories' Albuquerque and Livermore sites, and JPL's Edwards Air Force Base test facility.

I mention these because they are facilities which have been very critical to the development of parabolic dish systems components to this point. They collectively represent one of those areas that Government very definitely belongs in. Industry would not have built these facilities unaided simply because it is too costly; yet the net result is very much to the Nation's interest.

Future Federal role: I have heard several comments made today about what is the Government role, why we are involved, and I would echo Mr. Nelson's statement. Why are we involved? Because we are going to have another oil crisis. It might be next week, it might be 10 years from now, but we are going to have another one. Rather than being behind the eight ball when that happens, I think now is the time that we must do something about it. We have to start. We started in 1970; we had a panic in 1973; we had another panic in 1977–78; and we are going to have another one. That is the primary reason that I think the Federal Government belongs in renewable energy research, specifically in solar thermal electric research.

Where does industry fit? As I have stated, many component development demonstration programs have been highly successful, but in my opinion a true commercial market will not emerge until systems-level testing over an extended period, defined as 12 to 24 months, has taken place. Investors in the private sector are unwilling to supply the needed capital for a full industry development until full systems tests have been completed.

In these days of high interest rates, return on investments of 3 to 5 years is what companies are looking for, and we cannot legitimately talk about a solar thermal electric industry unless we are talking in the 6- to 10-year time frame. You just will not get private industry investment at a significant level, and the technology will not be developed if it is left strictly in private hands.

Again, I would endorse the performance of the Jet Propulsion Laboratory and the Department of Energy to date as technology development brokers. There are many questions. Would I have done it this way in this particular component development? I might have done it differently, but net I think that they have both done a very good job.

My recommendations: The previous administration convened a Domestic Policy Review Board on the energy situation in the United States. That board recommended a national goal of three quads of solar thermal energy by the year 1990. I believe that a congressional directive to the Department of Energy or its successor agencies to strive towards this goal would greatly enhance the prospects of commercializing parabolic dish systems. These systems could provide up to 1 quad of what the 3-quad goal set 4 years ago was.

Keeping that in perspective, in 1981 the United States consumed approximately 78 or 79 quads of energy. Solar-thermal parabolic dish systems could provide up to 1 quad of energy by the year 2000 if the development continues.

Again putting it in perspective, approximately 13 of the 78 quads of energy consumed in this country in 1981 were imported. They represent imported gas, oil, and other fuel stocks.

I recommend Federal support of a parabolic dish program at the $15 million a year level at least through fiscal 1985-86. With such support, parabolic dish technology could be fully tested and proven ready for commercialization. There seems to be a perception on the part of the administration that several solar thermal technologies are ready for commercialization. As a company that has been involved in this technology for over 8 years, I would state simply that that is not true. The technology is not ready for commercialization. There are several systems-level issues and certain component-level issues which must be resolved before commercialization can take place.

Cost-sharing by industry, once we get near the systems-level demonstration point or user-level demonstration point, could and should be required, but that will not come for another 3 years. With the level of support at $15 million a year through fiscal 1985-86, I believe that parabolic dish solar thermal technology could well supply upwards of 1 quad of the Nation's energy requirement by 1995, and this would represent displacement of the equivalent of 170 million barrels of oil per year.

Thank you.

Mr. **Fuqua**. Thank you very much, Mr. Shine.

We have a vote on the House floor. I think, rather than interrupt you in the middle of your testimony, Dr. Hildebrandt, we shall take another short recess while we vote and we shall be right back.

[Recess taken.]

Mr. **Fuqua**. The subcommittee will resume.

Dr. Hildebrandt, we will hear from you at this time.

Dr. **Hildebrandt**. Mr. Chairman, I am Alvin Hildebrandt, director of the Energy Laboratory and professor of physics at the University of Houston, and I am very pleased to have the opportunity to give testimony on the future needs of solar thermal research.

I have been involved in central receiver research since 1970. My comments will largely be on applied research needs for the central receiver technology in the eighties, but I would like to make a few comments on the program in general. Without a program goal, research is all too often of little value.

The Barstow 10-megawatt electric project is the culmination of 10 years of a very methodic program conceived, designed, and developed under four administrations. Considerable data have been obtained; cost estimates have been sharpened and, in many cases, lowered through research. General industry and the electric utilities in particular have obtained considerable knowledge and experience in the power tower concept.

Levelized busbar energy costs for a number of energy sources are shown in an attached figure. A 100-megawatt plant with a capacity factor of 60 percent would displace about 1 million barrels of oil annually and be competitive with other sources once we get a few of these plants built.

At the immediate present, the most important single item requiring consideration is the continuation of the 15-percent energy investment tax credit to 1992. This incentive is absolutely essential for the introduction of this technology until some $500 to $750 million of construction activity has occurred. Only a small part of this amount would actually be in the form of an incentive.

All new forms of energy have required some initial Federal cost sharing. Examples of other systems supported in the past by Federal funding are conventional nuclear, breeder, and fusion systems. It is not feasible just to produce a working apparatus for a utility, a prime first purchaser of new energy forms, and expect them to invest heavily in the system. Local ratepayers cannot be expected to finance national research, and public utility commissions will not allow it. Also, no single Fortune 500 equipment manufacturer can handle the activity required in the construction and development of this new power source.

Since 1973, the amount of funding to the solar thermal program for dishes, troughs, and central receivers has been between $500 and $700 million, I believe. If we were to include a fraction of the $500 to $750 million believed required for full commercialization, the cost of introducing this new energy system would be less than $1 billion. This is a small amount considering the minimum impact expected by 2000 of half a quad annually—1 quad is 170 million barrels of oil, I believe—in the electric sector, and up to 3 quads annually of process heat.

This would amount to 3 to 4 percent of our U.S. energy needs in 2000. Use would be largely in the Southwest, which cannot readily be supplied by present type nuclear.

To encourage a high level of activity in the electric areas, I believe, the Fuel Use Act should be waived for new plants beyond 1990, provided 50 percent of the budgeted energy is solar.

For the near term, the most important research areas involve reducing the risk so that manufacturers, third-party venture groups, and users such as the electric utilities can be brought together. Utilities cannot fund large research programs beneficial to outside groups, and manufacturers alone cannot fund a system in the present economic climate.

We can reduce the risk by testing of full-scale receiver panel-steam boilers in three forms of fluid transfer media. One is a sodium receiver, a salt receiver, and an advanced steam receiver. Events at Barstow and experiments at the Central Receiver Test Facility have given us considerable confidence in operation of heliostat systems and the once-through receiver-boiler system, but users cannot afford to build a new large-scale powerplant based on a scaled-up receiver-boiler component that has not been tested.

No surprises are expected, but designers should at least have the benefit of a full-scale component or subsystem test. Also, the repowering program is most helpful in risk reduction.

Basically, momentum must be maintained until the private sector is in fact building plants. Research funding for improvements in a number of project areas is needed as defined by Barstow and other results. These are: One, improvement in the reflectance and lifetime of mirrors; two, improvement of receiver absorptivity and lifetime; three, further reduction of heliostat weight by maintaining high-wind tolerance; four, improved storage systems to include an air-rock thermal storage system and chemical storage for process heat delivery; five, improved high-temperature materials, both metallic and ceramic; and six, utilization of dry-air cooling towers in the desert.

Research in these areas can significantly reduce energy costs, although they are not absolutely essential for the first one, or two, or several electric plants. Funds in these research areas will be essential in the next 5 years to bring central receiver electric systems to full commercialization.

Long-term research is required for the development of a process-heat utility similar to the electric utilities. Manufacturing companies find great difficulty in producing both their product and energy because of management complexity and their inability to raise capital. While process-heat utilities may supply manufacturers through cogeneration, the need remains for a heat utility capable of delivering a standard product such as 600° F, steam.

This could be accomplished through a chemical heat-pipe delivery system similar to that under development in Germany for delivery of nuclear high-temperature reactor heat. Heat would be transformed into chemical energy at the solar reactor and piped at ambient temperature to the user some 50 to 100 kilometers away. The user obtains chemical recombination energy from a catalysis reaction, and the transformed chemicals are piped back to the solar reactor in a closed system. Chemicals are never consumed but constantly converted and reconverted.

Additional applications of central receivers lie in the production of chemicals and fuels. Two obvious choices are low-temperature water-splitting cycles and the production of ammonia for agriculture. Low-temperature water-splitting cycles offer the potential of hydrogen production from water, a very desirable long-term fuel.

The production of ammonia from solar thermal is well suited for the desert Southwest and in Sun-rich areas of many developing countries. Ammonia is needed worldwide in agriculture. Solar thermal technologies are benign and relatively simple and will augment standard technology in many countries. Computers required to drive heliostats and perform other plant functions are sought by countries for other purposes as well.

The budget requirement for the next year, carefully considered and reviewed, has previously been considered in a Solar Thermal Energy Association document or fiscal 1983 budget recommendation. I concur with the group views. In general, I believe the amount of $60 million is required annually for full development of an energy source we know something about and for which we can make reasonable estimates.

A vigorous research program involving Government, universities, and industry is needed. Momentum must be maintained until plants are under construction.

There will be some budget decline as present solar electric systems are taken over by the private sector, but there will be a funding increase required in the out years as the research results on process heat, and fuels, and chemicals become available.

I would like to also make some brief comments on a workshop held on May 5, 1982, at the Solar Energy Industry Association headquarters in Washington, for the purpose of defining in broad outline the major thrusts that, from the viewpoint of the attendees, the Government should take in research on and development of solar thermal systems in the 1982 to 1990 timeframe. The meeting was attended by 18 people representing 17 different organizations.

The essential conclusion of the workshop is that the Federal Government, during the balance of the eighties, should support research and development of solar thermal systems that: One, produce liquid and gaseous fuels from nonrenewable and renewable feedstocks—these are hydrogen and carbon monoxide from $CO_2$; two, produce chemicals with special emphasis on reduction of energy costs in the production of current chemical products; and, three, show promise for affecting both near and long-term improvement in the cost of energy and efficiency in the production of electricity and process heat.

Principally within this category three but also partially in the others, Federally sponsored R&D work should emphasize the following technologies and/or products: I have mentioned energy storage, chemical heat pipes, component and subsystem cost reduction, but also they have included solar ponds and photon-induced processes where you directly use the solar spectrum and select exploratory experiments that potentially offer long-term payoff in terms of reduction of energy costs, conservation of fossil energy resources, and improvements in the quality of the environment.

In order to be able to carry out a meaningful R&D program for the 1980's and beyond, it was the consensus of the workshop attendees that test facilities are absolutely essential. Therefore, any R&D planning must include the financial resources to maintain and operate selected test facilities.

As a minimum, these facilities would be the Advanced Component Test Facility at Georgia Institute of Technology, the Central Receiver Test Facility in Albuquerque and, for the parabolic dish program, the test facility at Edwards Air Force Base.

There was a strong recommendation that the undertaking of the longer term R&D work by the Federal Government should be done in consonance with the completion by the Government of several ongoing technology programs that are close to being turned over to the private sector.

The recommendations made above for long-term R&D for the 1980's must not be construed as a recommendation that the Federal Government abruptly delete support for the central receiver, parabolic trough and dish technologies which are in the process of being taken over by the private sector. These three technologies must be phased in a logical, timely manner in accordance with the ability of the industry to accept and complete final development and to commercialize.

In closing, I wish to thank the committee for the opportunity to make this presentation.

Mr. FUQUA. Thank you, Dr. Hildebrandt.

Dr. Brown?

Dr. **Brown**. Mr. Chairman and members of the committee, I appreciate the opportunity to be here today.

I am manager of research programs for Arizona Public Service Co. Although APS is a moderate-size utility, it is the largest gas and electric utility in the State of Arizona.

As manager of research programs for that company, it is my responsibility to determine what new types of energy resources and related hardware we are going to need in the future that will provide tangible economic benefits to energy consumers. One of those technologies is solar energy.

The company has been involved in solar energy since 1954 when APS led in the formation of the Association for Applied Solar Energy, which today is the International Solar Energy Society. Since then, we have increased our involvement in solar energy to where we are involved in a large number of projects in solar domestic water heating, solar space heating and cooling, residential and central station photovoltaics, solar thermal electric, biomass, and wind.

Therefore, today I am coming to you to present a viewpoint from a prospective user of this technology, that is fairly heavily involved in its development.

The generation of electricity from solar energy is particularly significant. Electricity is a very versatile and transportable form of energy and therefore is extremely valuable. Of course solar energy converted into electricity can have the overall national benefits of helping to reduce our dependence on nonrenewable resources, particularly imported oil.

In my written testimony which I have submitted, I have offered some suggestions for the role of the Federal Government in the solar thermal electric areas that have been discussed earlier today such as solar trough technology, dish technology, and the central receiver.

Because of the time limitation, I will make my comments brief. I would like to concentrate my comments on the solar central receiver because, of all of the solar technologies that we have examined, that particular technology seems to hold, at least for us, the greatest potential for using solar energy in a practical and economical way.

Incidentally, I have added to my written testimony a reference document which discusses in considerably more detail the integration of solar technologies in the utility system, and some of the members of the committee might find this helpful in understanding the utility in relationship to solar energy systems.

As I said earlier, the solar central receiver, or the power tower concept, is the one that shows the most promise to us of having economic potential for large-scale applications of solar energy.

In addition to the benefit I mentioned earlier of helping reduce the use of renewable resources, particularly that of imported oil, the solar central receiver can be built in a fairly short time and in small increments compared to that of, say, coal and nuclear plants. This results in a benefit to our customers of a reduced cost for the funds used during construction compared to the conventional types of powerplants.

Also, the Sun, provides an inflation-proof fuel.

The technology to date is at the point now where the United States has a large experiment running at Barstow, Calif., the 10-megawatt Solar I facility. This project is a very important one in the sense that it demonstrates to the utilities and the potential manufacturers of this technology that the various components of a solar central receiver can indeed be brought together and made to work.

However, I might caution that this particular facility is not a commercial-scale demonstration. It does not contain commercial-type products. Therefore, it does not demonstrate by itself the commercial viability of the central receiver technology.

We need instead some further development in the area of research and development of the various components of this system, like the storage and the receiver systems, and we also need a large-scale, commercial-level demonstration before the utility industry will be in a position where they can purchase this technology as a part of their regular generation mix.

The role that the Federal Government will have in this experimental program we discussed is probably one of underwriting the risks. The utilities are in a position, because of regulatory constraints, to where we cannot put a great deal of money, R&D-type money, into high-risk items. Therefore, we are not in a position to participate in a big way in these high risk programs.

The manufacturers of these products are also constrained in some ways by the large amount of moneys required and the attendant risks. Also, there is a problem with incentive. Particularly in a solar central receiver, there are not very many areas where a company can put money into the development of these things and come out with a patentable device that gives them an edge in the market.

Therefore, any research performed tends to be generic, and this presents, I think, an ideal position for the Federal Government support because of the generic nature of the product that comes out of the R&D.

It does turn out, though, that there is a possibility for cost sharing. The utility industry can cost share particularly in the demonstrations to the degree that the demonstration has commercial value. Now, commercial value is somewhat difficult to define and particularly difficult to predict, but indeed there is a commercial value to most demonstrations if they produce electricity and hence a revenue.

I would like to discuss a little the nature of this commercial value. The Federal program to date has been heading along the lines of repowering technologies. Repowering is where a solar central receiver is built adjacent to an existing powerplant, preferably one that is fired by oil, and then use the solar energy to provide steam that would otherwise have been provided by the oil.

In this type of application, we have the lowest cost and the lowest risk approach to demonstrating this technology. However, it also happens to have potentially the lowest commercial value to the utility as a demonstration application. The reason is that it is strictly a fuel saver. Since it is being applied to an existing power plant, it does not defer or allow the utility to avoid adding capacity in the near future. It consequently does not have what is called capacity credit. The value of the repowering facility is therefore limited to what it saves in the way of fuel on the utility's system.

There is another approach also that could be taken, and that would be to build a full-scale commercial-size demonstration as a stand-alone system, where a new turbine is added to the solar system. This approach would have a higher cost and a higher risk, but it also turns out it has a potentially higher commercial value to the utility. Then not only does the utility have a fuel saver; it also has a new plant with capacity credit, which means now that the solar system can be credited with a deferment of other types of capital investment in the future such as, say, a coal plant or an oil plant or something like that.

Besides this demonstration, which is going to be required before I think utilities will commercially construct this technology and before manufacturers will put the investment into the factories required to build the components, we also need to have continuity in the Federal program in these earlier experiments that are going on at the various facilities like the Central Receiver Test Facilitv [CRTF] in Albuquerque.

We have been involved in R&D experiments at these facilities, such as the receiver and storage development, and design of the steam generators for these facilities, and we learned a great deal. It has given us some confidence that this technology can make it.

We have performed some studies that show that this technology can be economically available in the 1990's if we proceed along a healthy and rigorous R&D development path.

These studies have even shown that this technology has the opportunity, at least on our system, to compete with coal-fired generation used in an intermediate mode, that is, a fairly low capacity factor.

These factors cause us to be very excited about this technology. However, there is a great deal of uncertainty that exists and this is the role that the Federal Government has: to underwrite these risks by performing the experiments of the components, maintain the testing facilities that are needed to run these experiments, and then ultimately help with underwriting the risks of demonstration, in a cost-sharing mode.

Thank you very much.

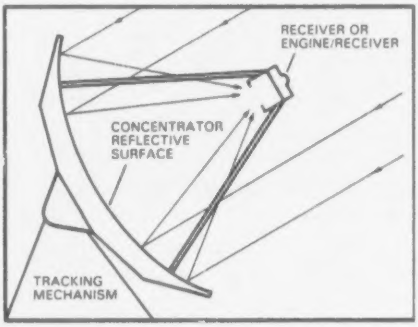
[The prepared statements of Mr. Shine, Dr. Hildebrandt, and Dr. Brown follow:]

# STATEMENT ON RENEWABLE ENERGY IN THE EIGHTIES: RESEARCH NEEDS FOR SOLAR ELECTRIC TECHNOLOGIES

Mr. Chairman, Ladies and Gentlemen of the Committee, Ladies and Gentlemen of the Staff:

I am pleased to accept your kind invitation to testify on my perception of the needs for federally-sponsored RD&D in renewable energy technologies over the next five years. There is indeed a need, particularly in the Solar Thermal Concentrating Collector area, if the U.S. is serious about reducing oil imports and achieving some measure of energy independence within the next decade.

My testimony will center on Parabolic Dish Technology. An illustration of a typical system follows.



Parabolic Dish Technology

Parabolic Dish Systems are one of several Solar Thermal Concentrating Technologies under development by industry and the U.S. Department of Energy. This type of system consists of a dish-shaped parabolic concentrator that focuses the sun's rays on a receiver (or absorber). The receiver is mounted above the dish at its focal point. The sunlight is focused on an opening in the receiver to heat a fluid or gas circulating through the receiver. The hot fluid can be transported to the ground for a variety of thermal uses, or direct electrical generation can be accomplished by integrating an engine/alternator with the receiver at the focal point.

With an engine/alternator mounted at the focal point, each dish can be a complete power-producing unit (module), which can function either as an independent system or as part of a group of modules linked to form a larger system. A single parabolic dish module can achieve fluid/gas temperatures from 300° to 1500°C and can efficiently produce up to 25 kW of electricity. Technical issues presently being addressed by DOE and industry are summarized below for the five principal dish subsystems.

Concentrator. The largest subsystem of a parabolic dish module is the concentrator, a shallow dish with a reflective surface that tracks the sun to focus sunlight on a receiver. Tracking along two axes ensures maximum solar energy collection during the day. Seven and eleven meter concentrators have been built and tested under DOE and/or industry sponsorship since 1977.

The conventional optical configuration for a dish concentrator is a paraboloidal mirror. The paraboloidal shape may, however, be segmented into a number of individual reflecting facets, which may be curved or flat.

The ability to reflect and focus sunlight is a principal consideration in selecting materials and designs for dish concentrators. The classical optical material used is back-silvered glass. Reflective materials typically must be curved, the exact shape of the facets dependent upon the design of the concentrator. Materials other than glass, e.g., aluminum or aluminized mylar, can be shaped more easily, but such materials have lower reflectivity than back-silvered glass. Other technical questions being addressed are bonding of the concentrator layers, degrading of surface materials in the outdoor environment, and decreasing concentrator weight and cost while maintaining strength.

Receiver. Because the receiver absorbs concentrated solar radiation at very high temperatures ( 2000°F), receiver materials must be developed that can withstand these and the potentially higher operating temperatures (up to 2700°F) of future dish systems. Several types of receiver have been developed and tested by DOE and industry since 1976. Additional research and development activities will concentrate on minimizing heat losses through the receiver opening (aperture).

Engines. Three types of heat engines are being tested for use with parabolic dishes: Brayton, Rankine, and Stirling. Heat engine designs for solar thermal-to-electric dish applications must be adapted for use in different attitudes due to the varying sun angle from sunrise to sunset. However, key development issues are the achievement of high engine performance and reliability, and identification of operating requirements at the interface of the engine and receiver.

Storage. For dishes providing thermal energy, periods of direct solar operation can be augmented by the addition of a thermal storage system. The storage media that has been most researched consists of oil/rock mixtures for use with the Rankine engine. Buffer storage (up to 1 hour) and intermediate storage (1 to 6 hours) can provide energy for dish systems during dark periods. Dishes operating in the Brayton or Stirling mode can be fitted with short-term thermal storage capacity (between the heat engine and receiver). The storage media will typically be a solid with high surface to volume ratios, e.g., ceramics, most frequently in a honeycomb configuration, when a Brayton or Stirling engine is used. These engines can be operated in a hybrid mode, where the engine runs on fuel, either fossil or renewable low BTU gas from biomass conversion, when sunlight is inadequate, providing a continuous source of electricity.

Controls. Dish systems track the sun in two axes. Each dish in a collector field is adjusted individually to ensure that the optimal amount of sunlight is being focused on the receiver opening. This requires the use of a computer-based active tracking mechanism to determine and maintain accurate alignment. Additionally, the control must regulate the engine/alternator in response to changes in the load requirement. This can be handled by appropriate modulation of the energy supplied by the Solar Receiver and/or the burner in a hybrid system. Other safety, and start-up/shutdown functional considerations must be automated.

The foregoing provides a short descriptor of the technology issues being pursued today.

## Sanders Associates and Sanders Solar Programs

Before presenting my views on a logical Parabolic Dish Program for the next few years, it would be appropriate to define briefly my company's past and proposed future role in the program.

Sanders Associates, Inc. is primarily engaged in the development, manufacture and sale of advanced technology electronic systems and products. Sanders conducts business in two principal industry segments, Government Systems and Products and Graphic Systems and Products. Sanders 1981 sales exceeded $360 million.

Sanders Government Systems and Products business includes defense electronics, component products, renewable energy systems products and international systems. The largest of these is defense electronics where Sanders is a leading producer of electronic and infrared countermeasures for aircraft self protection. Other defense markets include signal processing, ocean surveillance, air defense, training and simulation, and automatic test equipment.

Sanders has been part of the Solar Thermal R&D community since 1976. The company's principal effort in Solar Thermal has been in the development of high temperature receivers for Parabolic Dish and power tower applications. Sanders has been awarded slightly over $5M worth of R&D contracts by DOE since 1976. Sanders is presently under contract to DOE, through the Jet Propulsion Laboratory, to serve as systems integrator for an advanced technology 20$KW_e$ Parabolic Dish Brayton Power System.

Sanders has not yet entered the commercial marketplace with its equipment, and estimates that it is three to six years from such entry. Sanders has invested about $1 million of its discretionary resources in its solar technology over the past six years.

## Parabolic Dish System Benefits

Sanders Associates has concentrated on the development of Brayton engine powered Parabolic Dish Systems for a number of reasons, among them the following:

1. The Brayton Powered Solar Electric System promises to provide the lowest cost per delivered kW/hr compared with other systems;

2. Brayton engine technology is simpler mechanically than Stirling and Rankine technology;

3. The use of the advanced Brayton engine provides the highest (35%-45%) conversion efficiencies;

4. The Brayton uses ordinary atmospheric air where as the Stirling must use high pressure hydrogen or helium and the Rankine uses either water or an organic fluid;

5. Unlike the Stirling and small Rankine, the Brayton is currently being developed in appropriate sizes for Parabolic Dish applications, independent of the Solar Program for high volume commercial applications;

6. The modular nature of Parabolic Dishes grouped in farm-like clusters provide four powerful advantages to private industry in reaching commercialization:

   a. Only a small number of successful prototype modules need to be taken to proof of concept rather than to any large multi-megawatt scale;

   b. The ability of each module to be incrementally brought on-line permits short lead time on construction, negligible interest used during construction and rapid placement into a users rate base;

   c. Mass production benefits occur earlier and at a lower power market level due to the modularity of the 10-30 kW systems; and

   d. Additional modules can be added to farm-like clusters to meet the user's incremental power demand growth;

7. The minimal cooling requirements of the Brayton engines uniquely permit operation in the high insolation, arid regions of the U.S.

8. Multimodular systems permit routine maintenance and/or repair with only a partial output reduction.

### The Present Situation/Federal Role to Date

In my opinion, over the past six years, DOE has proven to be a rather effective technology development broker. The program Sanders is now pursuing under DOE auspices utilizes advanced technology components developed by a variety of industrial organizations under DOE and Jet Propulsion Laboratory sponsorship. Component demonstration programs have been very successful to date, clearly justifying the cost to DOE. These demonstrations have taken place primarily at Government owned and/or operated sites, utilizing facilities that industry would not or could not duplicate. No single company or industry could justify on a private use basis the JPL, U.S. Army, DOE, and Sandia operated Solar Thermal facilities which have been critical to the development of Solar Thermal Technology; specifically the Army White Sands site, Sandia's Albuquerque and Livermore sites, and JPL's Edwards Air Force Base test facility.

### Future Federal Role

Relative to the future Federal role, I believe that the Government should continue to support programs which will prove new technology at both the component and systems levels. Although many component development/demonstration programs have been highly successful, a true commercial market will not emerge until systems level testing over an extended period of time (12-24 months) has taken place. The reduced Federal role of recent years has delayed commercialization, particularly related to more advanced technology systems. Investors in the private sector are unwilling to supply needed capital until full systems tests have been completed. Further, in the Parabolic Dish System case, JPL has been the technology transfer medium. Withdrawal of DOE/JPL support will significantly reduce data flow between companies, as each component developer seeks to maximize his position vis-a-vis development of a system. Without a broker, technology development which is in the nation's long term strategic interests could be delayed.

Summary/Recommendations

The President's Domestic Policy Review (DPR) Board recommended a national goal of three quads (quadrillion BTU) for Solar Thermal Energy by the year 2000. I believe that a Congressional directive to the Department of Energy (or its successor agencies) to strive toward this goal would greatly enhance the prospects of commercializing Parabolic Dish Systems which could provide up to 1 quad of the 3 quad goal.

Over the past several years, DOE has been promoting what I perceive as an eight step program for advancing Solar Thermal Technology. Unfortunately, we are now stuck in the initial stages of Step 4, with little prospect for moving on. The eight steps are

1. Basic and applied research
2. Market research - perception of user requirements
3. Component development
4. Advanced System development and test
5. System engineering and field test
6. Test marketing - user test
7. Initial production of units and subsequent distribution
8. Sales and marketing

When a program moves beyond Step 4 and Step 5 to Step 6, cost sharing by contractors can logically be required by the Government. Until that time, very few if any component developers will be willing to invest substantial sums, not because the developers do not believe in the potential of the technology, but because the Return on Investment (ROI) requirements dictated by today's high interest rates preclude long term high risk investments. It is my belief that a 3-4 year commitment of $15-20 million per year to the Parabolic Dish Program will bring us to the point where industry and the financial community will be willing to invest substantial sums in commercializing a technology which could eventually save the U.S. 170 million barrels of oil per year.

In sum, Sanders recommends Federal support of the Parabolic Dish Program at the $15-20M a year level through at least FY85-86. With such support, Parabolic Dish Technology can be fully tested and proven ready for commercialization. Cost sharing by industry in the latter stages of this program should be required. With this level of support the parabolic dish solar thermal community could well supply upwards of 1 quad of the nation's energy requirement by 1995-2000, displacing the equivalent of 170 million barrels of oil per year.

# # # #

The accompanying photographs illustrate the Parabolic Dish Solar Thermal components and systems developed to date.

1. Sanders High Temperature Receiver under test at JPL Edwards Air Force Base Test Site

2. E Systems Test Bed Concentrator at JPL Edwards Air Force Base Test Site

3. E Systems TBC's at Edwards

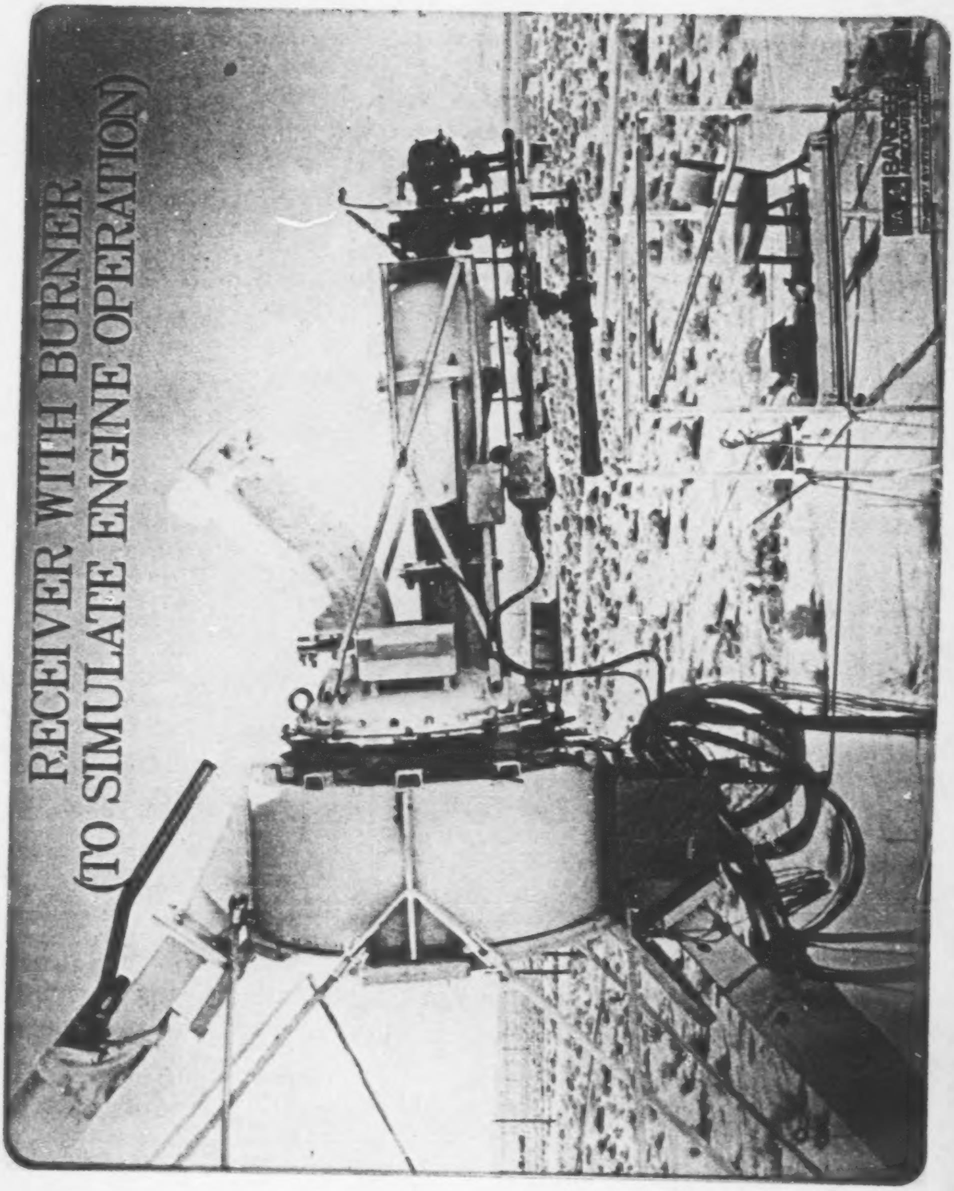
4. La Jet Concentrator

5. Garrett Corporation's Automotive Gas Turbine - Solarized AGT also under development

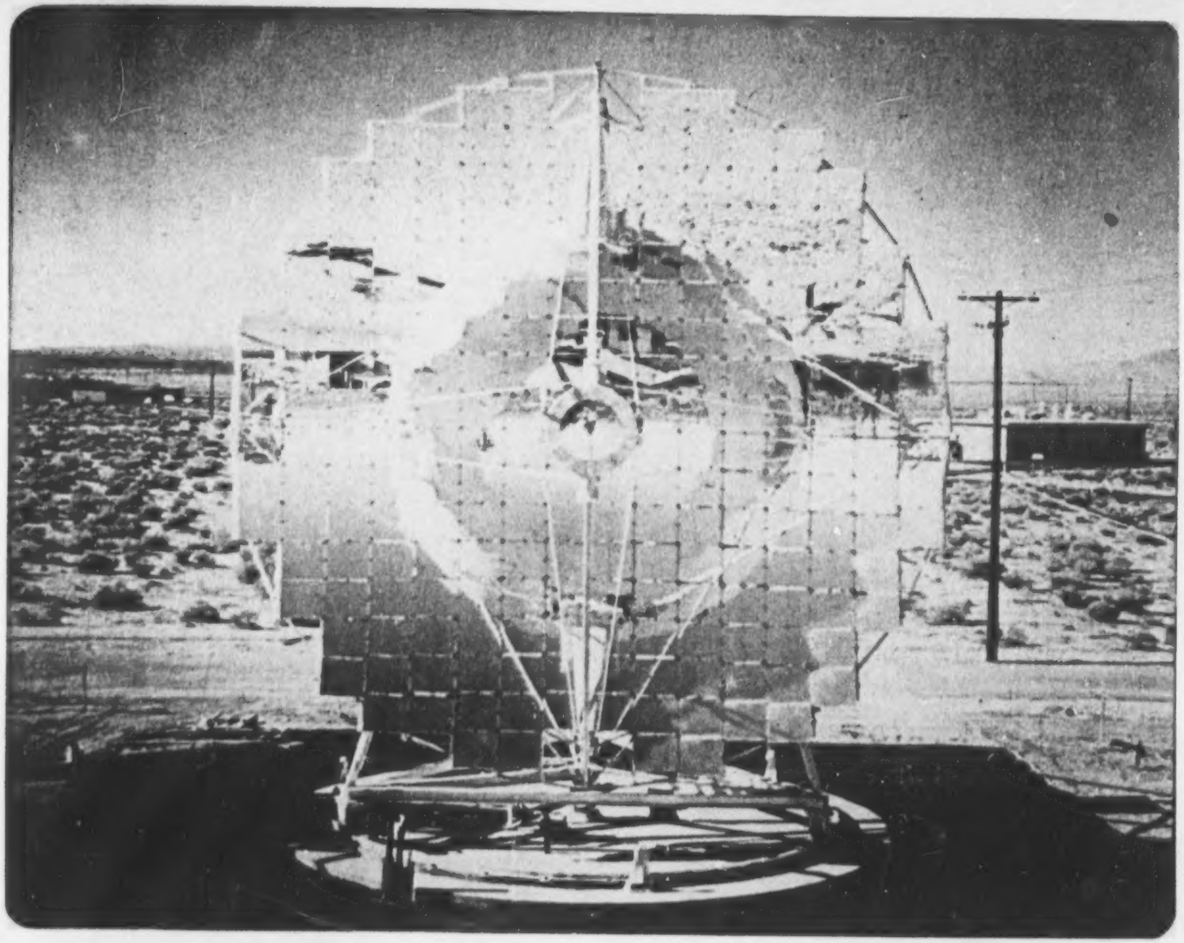
6. Detroit Diesel Allison Automotive Gas Turbine

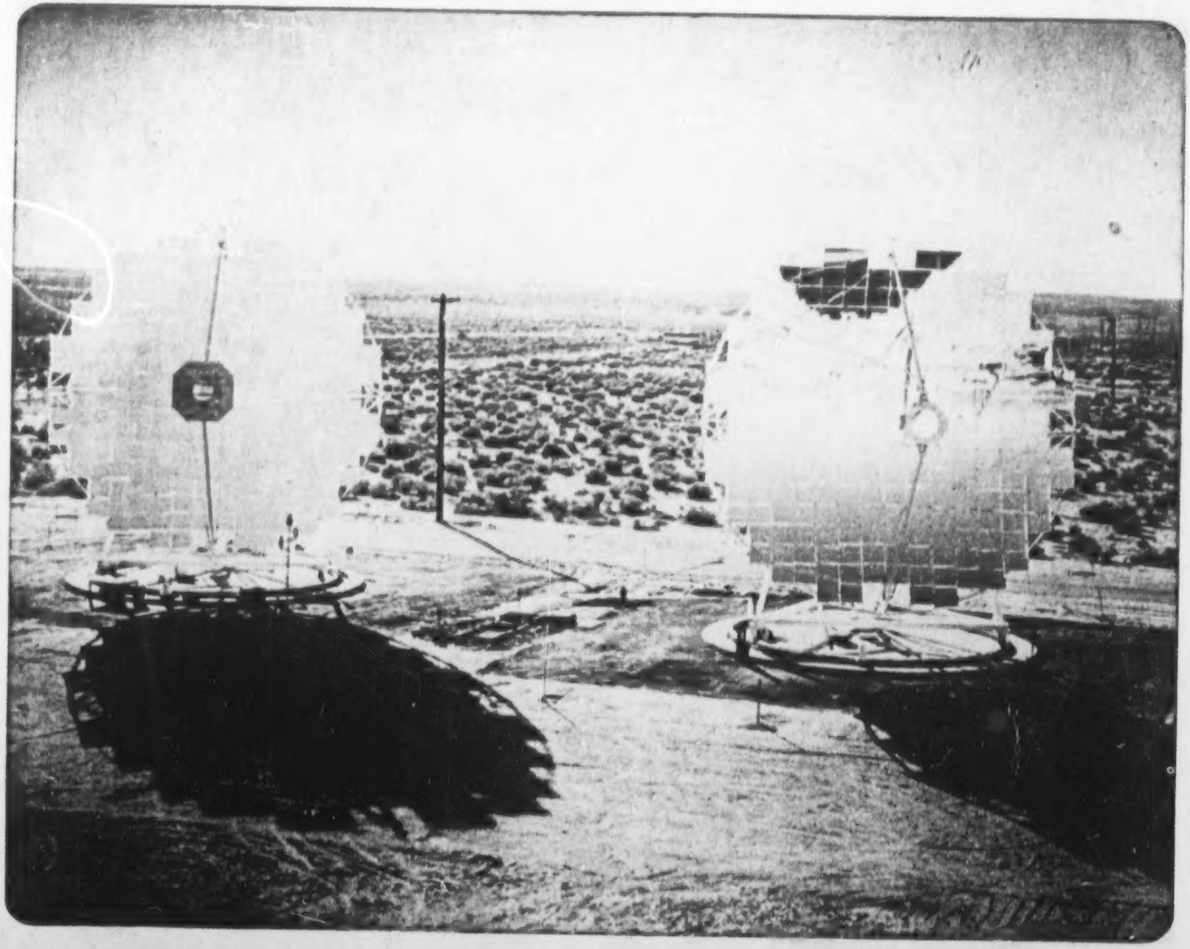
Daniel J. Shine, Jr. is Business Development Manager of Sanders Associates Energy Systems Center. Sanders is a major defense electronics firm located in Nashua, NH. The Company has been involved in Solar Thermal research for several years. Sanders has designed, built, and tested several solar thermal components for DOE, the Jet Propulsion Laboratory and Sandia Livermore since 1976 and is presently acting as systems integrator and high temperature receiver supplier in the Jet Propulsion Laboratory's Brayton Turbine Parabolic Dish Module Program.

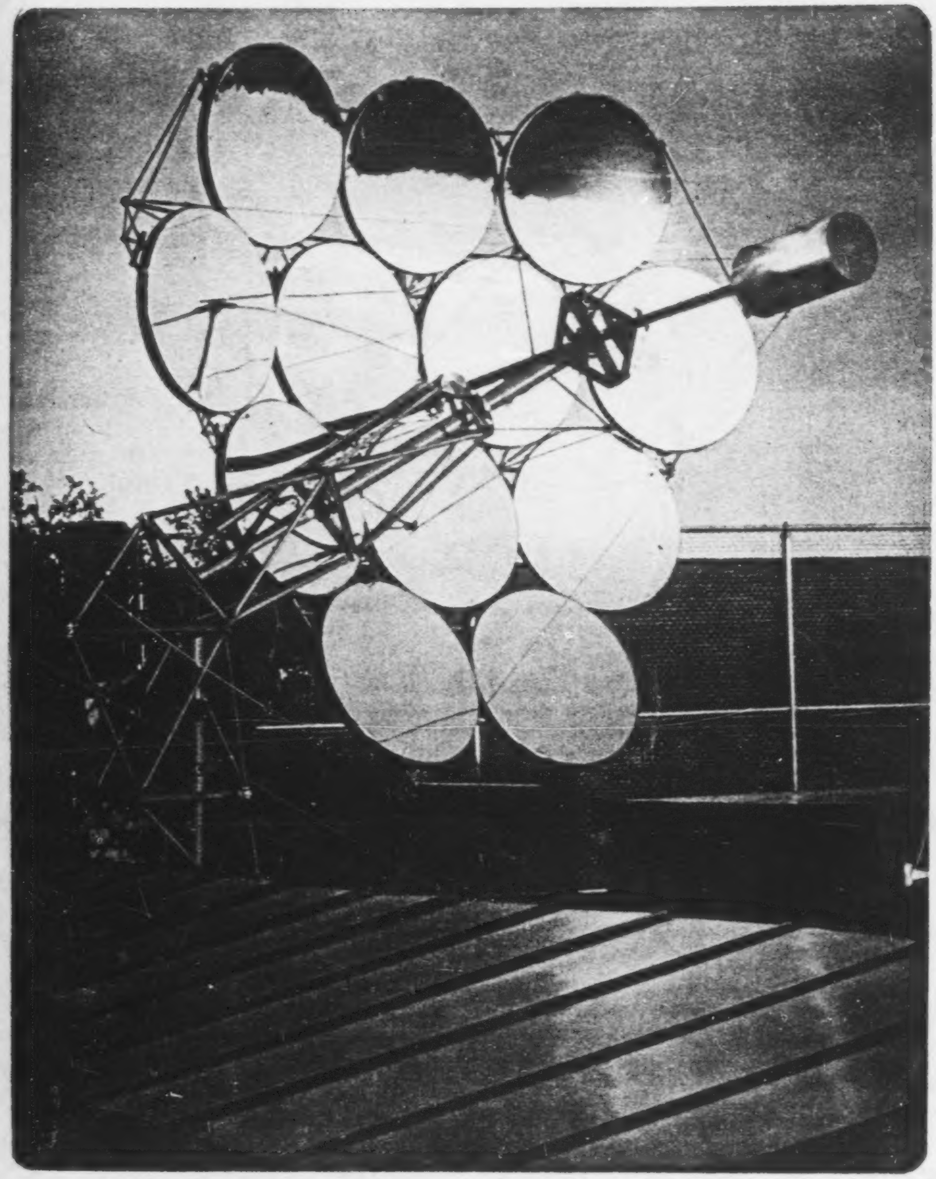
Mr. Shine is a founder and Board Member of the Solar Thermal Energy Division of the Solar Energy Industries Association and is presently Chairman of the Division's Point Focus Committee. Prior to joining Sanders in 1976, he spent ten years in the Federal Government in various technology evaluation positions. Mr. Shine is a graduate of Merrimack College, North Andover, Massachusetts and holds an MS from Georgetown University's Graduate School of Foreign Service.



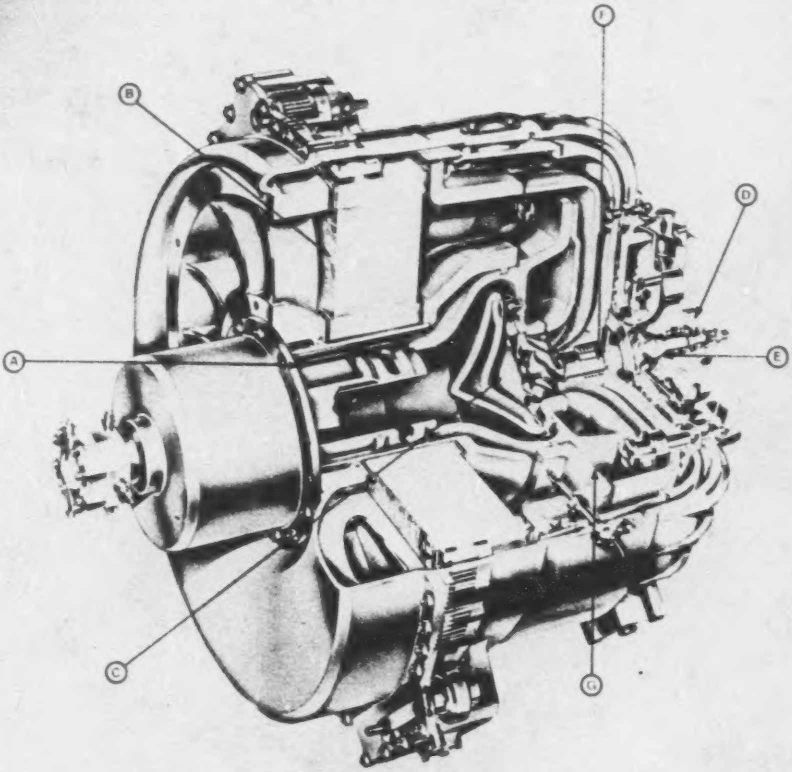
RECEIVER WITH BURNER
(TO SIMULATE ENGINE OPERATION)







**AGT101 POWER PLANT**



**A. Combustor**
- Premix/Prevaporizing Variable Geometry
- Ceramic Material

**B. Regenerator**
- Ceramic Material
- Rotary—Extruded Matrix
- Developed Seals and Bearings

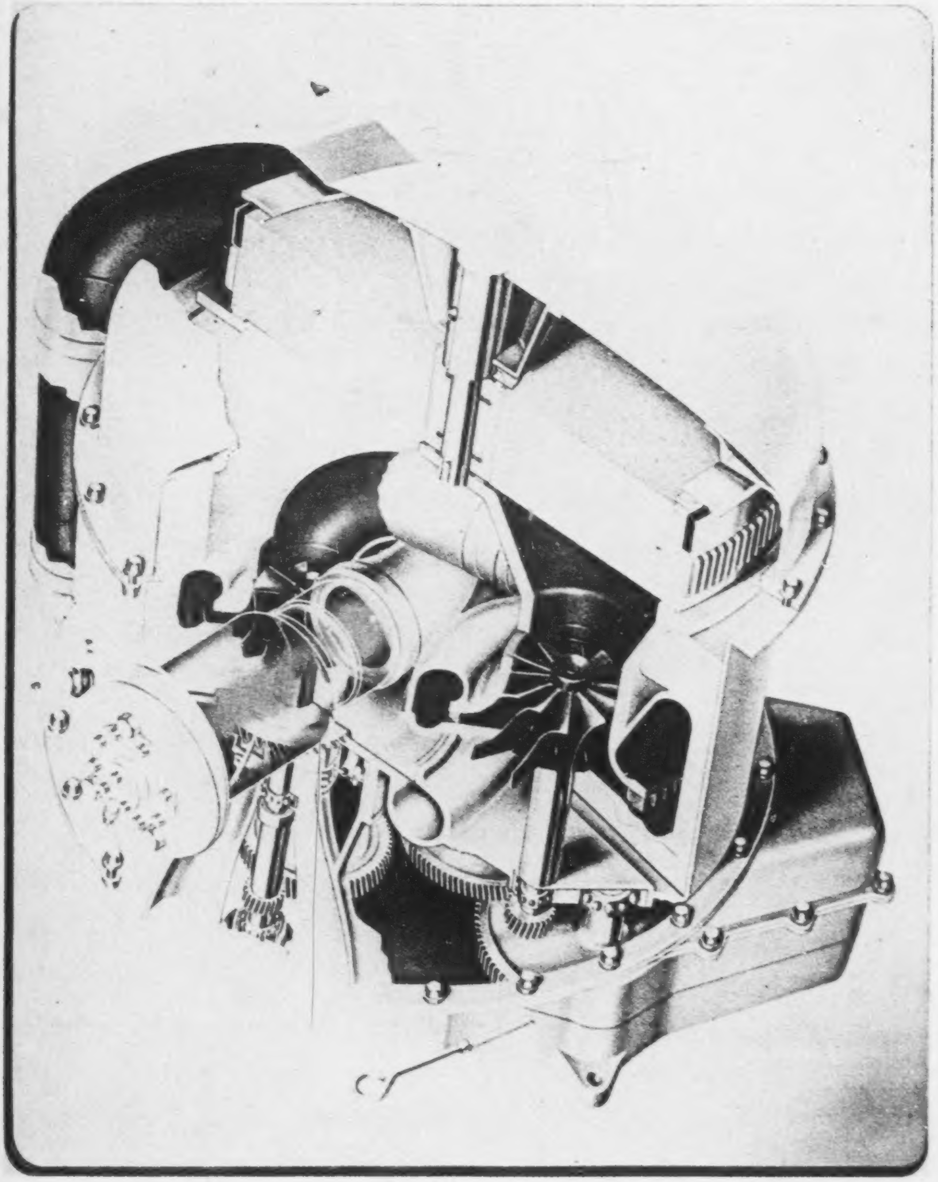
**C. Turbine**
- Single Stage, High Work Radial
- Ceramic Material
- 2500°F Maximum Turbine Inlet Temperature

**D. Ball Bearing**
- Radial and Thrust Loads

**E. Compressor**
- Single Stage Centrifugal
- 5:1 Pressure Ratio
- Powder Metal Aluminum
- Variable Inlet Guide Vanes

**F. Foil Gas Bearing**

**G. Ceramic Structures**
- Transition Liners, Turbine Shroud,Turbine Stator
- Materials include RBSN, Sintered SIC, RSSIC



# RESEARCH NEEDS FOR THE CENTRAL RECEIVER TECHNOLOGY IN THE EIGHTIES

Alvin F. Hildebrandt
Energy Laboratory
University of Houston
Houston, Texas 77004

I am Alvin Hildebrandt, Director of the Energy Laboratory and Professor of Physics at the University of Houston, and am very pleased to have the opportunity to give testimony on the future needs of solar thermal research. I have been involved in central receiver research since 1970. My comments will largely be on the research needs, but I would like to make a few comments on the program in general. A review of aims and achievements will be given of the central receiver program where applications have proven the quality of the research. Without visible application as a goal, research is all too often of little value.

The Barstow 10 MWe pilot project is the culmination of ten years of a very methodic program conceived, designed, and developed under four administrations. Considerable data have been obtained; cost estimates have been sharpened and, in many cases lowered, through research. General industry and the electric utilities, in particular, have obtained considerable knowledge and experience in the Power Tower concept.

Levelized Busbar Energy Costs (BBEC) for a number of energy sources are shown in the attached Fig. 1. This data has been supplied by the Rockwell ESG Group. Curves are shown for heliostat costs of $200, $100 and $78 per square meter. The heliostat costs form a major part of Solar Central Receiver plants. At present a realistic cost is believed to be $175 per square meter for a purchase of 17,000 units, the number appropriate for a single 100 MWe plant with a capacity factor of 60%. Such a plant would displace about 1 million barrels of oil annually.

At the immediate present, the most important single item requiring consideration is the continuation of the 15% Energy Investment Tax Credit to 1992, and the continuance of the Business Tax Credit. These incentives are absolutely essential for the introduction of this technology until $500-750 million of construction activity has occurred. Only a small part of this amount would actually be in the form of an incentive. All new forms of energy have required some initial Federal cost sharing. Examples of other systems supported in the past by Federal funding are conventional nuclear, and now breeder and fusion systems. It is not feasible to just produce a working apparatus for a utility, a prime first purchaser of new energy forms, and expect them to invest heavily in the system. Local rate payers cannot be expected to finance national research, and public utility commissions will not allow it. No single Fortune Five-hundred equipment manufacturer can handle the activity required in the construction and development of this new power source.

Since 1973 the amount of funding to the Solar Thermal Program for dishes, troughs, and central receivers has been $500-700 million. If we were to include a fraction of the $500-750 million believed required for full commercialization, the cost of introducing this new energy system would be less than $1 billion. This is a small amount considering the minimum impact expected by 2000 of 0.5 quads (1 quad = $10^{15}$ BTU) annually in the electric sector and up to 3 quads annually of process heat. This would amount to 3-4% of our U.S. energy needs in 2000. Use would largely be in the Southwest which cannot readily be supplied by present type nuclear.

Solar energy can make a first impact upon intermediate capacity electric power. It promises some baseload applications through air-rock storage and chemical storage development. To encourage activity in the electric areas, the Fuel Use Act should be waived for new plants beyond 1990, provided 50 percent of the budgeted energy is solar. This requirement would ensure prudent use of the gas and oil and more rapid development of Solar Central Receiver plants.

## NEAR TERM RESEARCH

For the near term, the most important research areas involve reducing the risk so that manufacturers, third party venture groups, and users such as the electric utilities can be brought together. Utilities cannot fund large research programs beneficial to outside groups, and manufacturers alone cannot fund a system in the present economic climate. We can reduce the risk by testing of full scale receiver panel-steam boilers in three forms - a salt receiver, a sodium receiver, and an advanced steam receiver. Events at Barstow and experiments at the Central Receiver Test Facility have given us considerable confidence in operation of heliostat systems and the once-through receiver-boiler system, but utilities can not afford to build a new large-scale power plant based on a scaled up receiver boiler component that has not been tested. No surprises are expected, but designers should at least have the benefit of full scale component or subsystem tests. Such an effort is expected to cost in terms of $10-15 million, but at least an order of magnitude less than the Barstow project.

Research funding for improvements in a number of project areas are needed. These are: (1) Improvement in the reflectance and lifetime of mirrors, (2) Improvement of receiver absorptivity and lifetime, (3) Further reduction of heliostat weight while maintaining high wind tolerance, (4) Improved storage systems to include an air-rock thermal storage system and chemical storage for process heat delivery, (5) Improved high temperature materials, both metallic and ceramic, (6) Utilization of dry air cooling towers in the desert, (7) Detailed analysis and reduction of operation costs of Central Receiver systems. Since a number of skills for several shifts are required daily, a minimum size plant is required for economic energy production, (8) Automation of plant operation through computerization. Considerable labor and O & M costs can be effected.

Research in these areas can significantly reduce energy costs although they are not absolutely essential to the first several solar electric plants. Funds in these areas will be essential in the next five years to bring Central Receiver electric systems to full commercialization.

## PROCESS HEAT, FUELS AND CHEMICALS

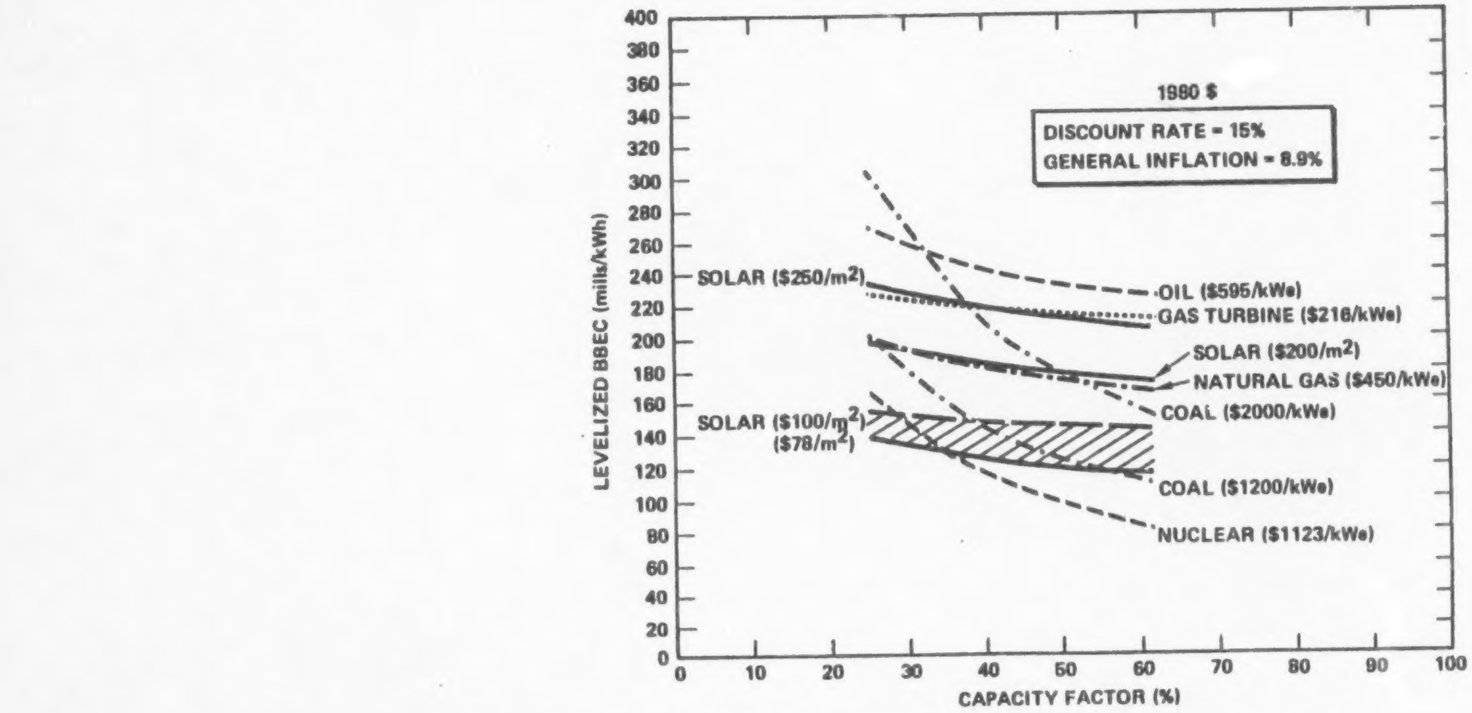
Long term research is required for the development of a process heat utility similar to the electric utilities. Manufacturing companies find great difficulty in producing both their product and energy because of management complexity and their inability to raise capital. While process heat utilities may supply manufacturers through cogeneration, the need remains for a heat utility capable of delivering a standard product such as $600^{\circ}$F steam. This could be accomplished through a chemical heat pipe delivery system similar to that under development in Germany for delivery of Nuclear High Temperature Reactor heat. Heat would be transformed into chemical energy at the solar reactor and piped at ambient temperature to the user some 50-100 kilometers away. The user obtains chemical recombination energy from a catalysis reaction, and the transformed chemicals are piped back to the solar reactor in a closed system. The chemicals are never consumed but constantly converted and reconverted.

Additional applications of central receivers lie in the production of chemicals and fuels. As we gain more experience in the operation of central receivers, we are discovering more uses of this non-polluting energy source. Two obvious choices are low temperature water-splitting cycles and the production of ammonia for agriculture. Low temperature water splitting cycles offer the potential of hydrogen production from water a very desirable long term fuel. The production of ammonia from solar thermal is well suited for the desert Southwest and in sun rich areas of many developing countries. Ammonia is needed world wide in agriculture. Solar thermal technologies are benign and relatively simple and will augment standard technology in many countries. Computers required to drive heliostats and perform other plant functions are sought by countries for other purposes as well.

The budget requirement for the next year, carefully considered and reviewed, has previously been considered in a Solar Thermal Energy Association (STEA) document. I concur with the group views. In general, I believe the amount of $60 million is required annually for full development of an energy source we know something about and for which we can make reasonable estimates. A vigorous research program involving Government, Universities and Industry is needed. There will be some budget decline as present solar electric systems are taken over by the private sector, but there will be a funding increase required in the out years as the research results on process heat and fuels and chemicals become available.

In closing I wish to thank the committee for the opportunity of making this presentation.

# BUSBAR ENERGY COST COMPARISONS



Rockwell International
Energy Systems Group

FIG. 1 BUSBAR ENERGY COSTS VS CAPACITY FACTOR FOR A NUMBER OF ENERGY SOURCES.

81-J20-9-5A

# TESTIMONY BEFORE THE HOUSE SCIENCE AND TECHNOLOGY COMMITTEE

Testimony of

Merwin L. Brown, Ph.D.
Manager of Research Programs
Arizona Public Service Company

before the Energy Development and
Applications Subcommittee of the House
Committee on Science and Technology

Washington, D.C.

July 28, 1982

Mr. Chairman, Members of the Committee:

I am Merwin L. Brown, Ph.D., Manager of Research Programs for Arizona Public Service Company (APS). The Company is committed to the development of solar and other energy sources that will provide economic or other tangible benefits to energy consumers. APS has been involved in the development of solar energy since 1954 when APS officials led in the formation of the Association for Applied Solar Energy, now called the International Solar Energy Society (ISES). Today APS is conducting or participating in over 20 solar R&D projects including domestic water heating, space heating and cooling, residential and central station photovoltaics, solar thermal electric generation, wind, biomass, and solar resource monitoring. In most of these activities we work closely with other utilities, industry manufacturers and suppliers, universities, joint R&D groups, and local, state, and federal government organizations and contractors. Notable among these activities are the Sky Harbor Photovoltaic Project, the Saguaro Solar Repowering, and the SOLERAS Solar Rankine Cooling/Co-generation Demonstration.

I am here today to discuss the future of solar thermal electric generation and the role that the federal government should play. Recent developments convince us that solar thermal electric power plants can be commercially available within the decade. There is a critical role for the federal government, especially in the form of underwriting risk, to assure that this desirable electric generation resource becomes available.

The rising prices and impending depletion of conventional fuels, chiefly oil and natural gas, have created a global impetus for developing solar energy, along with other energy resources such as coal, nuclear, and geothermal. Among the many potentially useful forms of solar energy is the generation of electricity, which is versatile, transportable and of high value. A 100 MW solar electric power plant operating in Arizona could generate the equivalent energy supplied by 100,000 solar hot water heaters at about the same or slightly lower cost. Furthermore, a customer, located hundreds of miles away, could use the electricity not only for heating water, but also for lighting, space conditioning, and running appliances. Of great importance to the utility customer's point of view, solar power plants can be built in shorter times and in smaller incremental additions than coal and nuclear plants, significantly reducing the cost of funds used during construction. The fuel is indigenous and inflation proof.

As a practical matter today, there are two choices for converting sunlight to electricity: photovoltaics and thermal. APS is heavily involved in the development and testing of both of these processes, but here I will only discuss solar thermal.

For Southwest utilities, the solar thermal electric process appears to offer the best promise for making a reliable, economic contribution to their generation capacity. In this process, a fluid, heated in a solar collector such as flat plate, solar pond, a trough or bowl concentrator, or a central receiver, is used to generate electricity in turbomachinery, much as in a conventional power plant. A very important feature of most solar thermal electric systems is that relatively inexpensive thermal energy storage can be incorporated to make it possible for solar to provide electricity when the customer demands it, significantly increasing its value. In general, the economics of thermal systems improve as the efficiency increases, efficiency increases with higher temperatures, and higher temperatures are produced by concentration of sunlight. Thus, trough, bowl and especially central receiver solar concentrators have received the most interest.

Trough solar collectors produce a medium temperature fluid that can be used for many industrial process heat applications and some electrical production. The technology is relatively simple, easily manufactured and is now being produced at a commercial level. The relatively low temperatures produced in trough collectors result in low efficiencies of conversion to electricity. This fact hampers economical electrical generation on the grid, but does not preclude many industrial process heat and some non-utility, site-specific electric production applications. Since the technology as a system is generally well developed and demonstrated, the federal role should emphasize funding basic materials R&D for items such as advance coatings for thermal receivers and improved reflective surfaces for the mirrors.

The higher temperatures and, therefore, greater electrical conversion efficiencies of bowl or dish concentrators have created an interest in electrical generating systems using this solar collector concept. Investigations and design studies have focused on relatively small sized plants consisting of many small generating modules. As an exception within the family of solar thermal systems, the dish concentrator concepts do not incorporate energy storage. This fact limits the ability to deploy dishes as a reliable contribution to electric generating capacity. Additionally, due to a potential for high maintenance cost of a large number of small components, this concept appears to have limited opportunities for economic success for large scale utility use. There appears, however, to be some potentially economical applications, such as a fuel saver in utility systems, especially those using oil, or as a small dedicated generator at locations remote from the utility grid. Dish systems have been proposed for small communities. Federal assistance might be appropriate for R&D on advanced electric conversion equipment proposed for dishes, such as Brayton and Stirling engines, and on high temperature receiver materials and improved reflective surfaces. Additional system testing and a small demonstration of a few hundred kilowatts will probably be required before dish systems can be evaluated for commercialization.

Of all the solar thermal electric concepts, the central receiver or power tower has emerged to have the greatest potential for achieving a commercial status for large scale electrical generation from solar energy. This concept heats a fluid in a receiver atop a tall tower, hundreds of feet high, surrounded by a field of thousands of tracking mirrors, called heliostats, that reflect sunlight to the top of the tower. These mirrors are typically shaped in a square about 20 feet on a side and collectively produce concentrations of over a thousand suns. The thermal energy is used to produce steam or a heated gas for turbines which drive generators to produce electricity. The thermal energy in the collecting fluid can be stored for later use. If needed, a fossil-fired back-up can be relatively easily integrated into the plant, giving it an exceptionally high availability. Our studies, however, indicate that storage is generally preferable.

Several central receiver designs have been developed, characterized for the most part by their heat transfer fluids: water/steam, molten salt, liquid sodium, air, and helium. The selection of transfer fluid influences the receiver design, thermodynamic cycle and the mode of storage. In the water/steam and gas concepts the fluid can be conveyed directly through the steam or gas turbine. In the molten salt and sodium systems the hot fluid is used to produce steam in a steam generator for use in the turbine.

The water/steam central receiver option is being demonstrated by the 10 MWe Solar One plant at Barstow. The plant represents first generation central receiver technology. It is not representative of plant efficiencies that can be obtained using present day steam turbines and is not considered to be a demonstration of a commercial system. Solar One, however, will provide the valuable function of showing that the central receiver is a viable operating system and that all subsystems, such as the collector, receiver, storage, and controls, can operate in concert with the electric power generation equipment like the turbine generator, condenser, and pumps.

Of more significance ultimately to utilities are the advanced central receivers, which offer the promise of higher efficiencies, low-cost thermal storage, and cost reductions. Current near-term engineering design efforts are being directed to the use of advanced water/steam, molten salt, and liquid sodium systems for solar repowering. In solar repowering, a solar thermal plant is placed adjacent to an existing oil/gas fired plant and used to generate steam for the existing plant's turbine when energy from solar is available, thus displacing oil and natural gas.

In 1978, Public Service Company of New Mexico, under contract to the Department of Energy, conducted a technical and economic assessment of repowering to determine the potential for solar repowering. The resulting market survey indicated that at a

50 percent repowering level, the potential market in the southwest U.S. would be approximately 5000 MWe.

In addition to the potentially large market, the repowering arrangement provides what is probably the cheapest and lowest risk R&D approach to developing the solar central receiver technology. The construction of one or more 50 to 100 MWe solar facilities at existing oil/natural gas-fired power plants, such as the facility we are designing for our Saguaro power plant, would not only demonstrate repowering, but stand-alone solar plants as well. Such tests would prove advanced components, stimulate industrial production, and give the utilities much needed data for making planning decisions about the utilization of solar power plants.

In addition to engineering work, experiments for developing and testing components such as the receiver, storage and steam generator are being conducted and planned as part of the advanced development program. There remains the need for a commercial scale (about 100 MWe) demonstration to prove that the technology can operate as designed and that full scale plants can be commercially constructed.

Among the renewable energy options under development in this country, the solar central receiver promises to be the most important contributor to the future energy needs. It offers attractive economics and adaptability to industrial heat and fuel production needs as well as large scale electric power generation. Depending on the urgency of the development program, this generation option is expected to be economically competitive on many utility systems before 1990. Through our involvement in many studies, design efforts and component testing, APS has concluded that the solar central receiver has a high probability of being economically competitive with oil-fired generation and with most new coal-fired generation used in an intermediate load range. However, until the ability of mass production to bring down the cost of heliostats and attainment of the expected performance of the total system for conversion of sunlight into electricity are confirmed by demonstration, there remains uncertainty in predicting ultimate commercial success. If we are to have this valuable option there must be a concerted effort by utilities, manufacturers and the government to complete development and testing of components, continue engineering, and demonstrate the commercial-sized units.

The Nation's utilities, individually and collectively, are restricted by state regulatory policies from attracting the financing necessary to undertake projects involving large financial risks. Manufacturers are similarly restricted from collectively participating in such activities. Although constrained by the relatively large sums of money required and the long time required for the return on investment, private enterprise can, however, fund a significant portion of the cost of demonstration once the basic R&D, component testing and engineering are complete. Utilities can cost share by financing a plant to the degree that it has commercial value. Federal assistance is necessary, however, to underwrite the risk of the first-of-a-kind demonstration of such a plant.

The federal program has been directed toward a solar repowering demonstration, Because it uses the existing turbo-machinery, this approach has the lowest cost and risk for demonstrating the central receiver and applies to future stand-alone applications as well as repowering. Our studies estimate the cost of a minimum-sized demonstration of 60 MWe beginning in 1987 to be about $145 million in 1983 dollars. Because repowering uses an existing plant, commercial value cannot be given for capacity credit and if the existing facility is old the life of a repowered plant might be limited. Considering these factors, the commercial value is derived from the fuel savings. Depending on the location, type of utility, the amount of oil saved relative to coal and nuclear, and other factors, an electric utility might be able to fund up to 50 percent of the cost. The government's share of about $70 million would be spread through 1987, with most of the funding required in 1984 and 1985.

Another option would be to build a commercial-scale 100 MWe stand-alone plant as a demonstration at a cost of about $280 million in 1983 dollars. Although the total cost and risk would be greater than a repowering demonstration, the commercial value would be relatively higher because of the capacity credit of the new plant. Again depending on various factors, our studies show that an electric utility might be able to fund up to 80 percent of the cost of the new plant.

Critical to the commitment of private industry dollars is assurance of continuity of federal funding. Component development and testing this year and next is especially important for the much larger commitment by utilities and private industry for the future. The large expenditures by industry in manufacturing plants must be made on faith in the future. The Congress can help remove the current uncertainty.

In the past two years, we have participated in federally-funded tests of molten salt receivers and storage, and believe these projects to be of great value towards reducing the risk of building a commercial-scale demonstration. We are currently involved in organizing an industry/government cost-shared project that will test the integration of advanced components into a small 750 kW molten salt solar plant at the Solar Central Receiver Test Facility in Albuquerque. The Congress is strongly urged to maintain important solar research facilities such as this one in Albuquerque so that these valuable tests can be completed.

In conclusion, as a result of the hundreds of millions of dollars spent to date by private industry and local and federal governments, the solar central receiver has emerged as a potentially viable generating resource. It can help reduce our dependence on nonrenewable fuels, especially imported oil, and contribute to the electric generating capacity of the United States. Only a relatively modest amount of R&D commitment remains to complete the task. Since it is necessary that the federal government underwrite the risk of this undertaking, we strongly urge the Congress to maintain a program that allows the successful completion of development and testing of components and provides cost-shared direct participation in necessary demonstration.

# Solar Power - Integration into Our Energy Systems

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## INTRODUCTION

The rising prices and impending depletion of conventional fuels, chiefly oil and natural gas, have created a global impetus for developing solar energy, along with other energy resources such as coal, nuclear, geothermal, and so on. The utilities of the U.S. have increased their support of developing solar applications through the years to the point that today hundreds of utilities are participating in more than 900 solar projects. Some of these solar applications will be owned by utility customers who will require the utility as a backup. The utility needs to know the potential impact of these solar applications and how they should be designed and used for proper integration with the grid.

The thing all solar devices have in common is their reliance on the sun. As trivial as that statement might appear, understanding its implications is the key to understanding the potential economics and degree of usefulness of solar energy.

## THE SPECTRUM OF SOLAR ENERGY

The term "solar energy" is too nebulous to be very definitive. Taken out of context, as it frequently is, it means different things to different people, and often the result is confusion. This situation partly exists because solar energy appears on earth in a broad spectrum of forms and uses.

Solar energy is captured by being converted to other energy forms by one of three mechanisms: chemical reaction, thermal excitation, or photovoltaic effect. It might appear in a transition (natural) form, such as wind, hydro, ocean thermal gradients, or biomass (including food, wood, fossil fuels, etc.). Added to this list are the many direct uses, which are the more popular concepts of "solar energy," such as swimming pool and domestic water heating, home heating and cooling, industrial process heat, irrigation pumping, and power generation.

The popular appeal of solar energy is as broad as its spectrum of applications. For all practical purposes, the sun is an eternal, "renewable" source of energy. Succinctly, when the sun goes, we go. Its energy is delivered relatively uniformly around the world, and compared to other energy resources, solar energy, except perhaps for the fossil forms, is reasonably accessible in at least one of its forms, even on an individual basis. Finally, the environmental consequences of most solar applications are relatively benign. These positive aspects have led many people to believe that solar energy is free, nonpolluting, and in general can immediately solve all of our energy problems; none of which is strictly true.

Sunlight, occurring at a maximum power of about one kilowatt per square meter on earth, is a relatively dilute energy source. Most conventional energy devices function at power densities roughly one hundred to a thousand times greater. Solar devices consequently require relatively large areas of material for collecting the energy, a requirement which usually translates into high costs.

Weather patterns and the earth's rotation make the sun an unreliable energy source on earth by reducing the quantity and availability of energy. Water vapor, dust and chemical compounds in the atmosphere adversely affect the quality of sunlight, reducing its effectiveness, especially in solar collectors using concentrating mirrors and lenses.

Although solar applications on the whole have small environmental impacts, they cannot be ignored. There is potential for environmental pollution arising from the industrial processes that manufacture solar components, some of which could foreseeably have large adverse consequences. Impacts arising directly from applications range from siting considerations of large-scale solar devices to the contribution to indoor pollution and individual safety hazards of solar applications in the home. Although these deficiencies must be addressed before widespread deployment can occur, the fact that solar energy is essentially inexhaustible, relatively clean, and more or less uniformly available in one form or another justifies attempts to develop it for judicious use.

## DIRECT APPLICATIONS OF SOLAR ENERGY

The applications for solar collecting devices can be separated conveniently into on-site and central station generation. Although the terms appear to be self-explanatory, the distinction between them can be uncertain in some instances. On-site applications usually are in the form of water heating, space heating and cooling, process heat, roof-top photovoltaics, and total energy supply, i.e., combined electric and thermal needs. Central station generation usually amounts to converting sunlight on a large scale into readily transportable forms such as electricity or "combustible" fuels.

### On-Site

A utility can generally take two positive approaches to on-site solar applications. One is to consider including them as a part of the utility service where legally and economically acceptable. More likely, customers will provide their own solar hardware, and it behooves the utility and its customers to make certain that these installations are optimized with respect to the entire customer-utility system so that overall lowest cost is achieved and system reliability is not compromised.

Because people generally need energy when the sun is not available, most solar devices require backup, usually the utility. Improper solar designs, however, can create uneconomical situations, especially if backup is required during utility peak power demands. Supplying peak power is very expensive, and most utilities are trying to reduce these uneven demands for power.

While having the potential for adding to the problem, some solar devices, if properly designed, have prospects for reducing or helping to meet costly peak demands. Those solar applications such as domestic water heating, space heating and cooling, and thermal electric generation, that can sometimes use thermal storage, promise, or in a few cases have exhibited, some potential for this role. Other devices, like wind and photovoltaics, that require electrical storage which now is quite expensive, do not now show as much promise, but might serve as fuel savers.

## Small, Dispersed Solar Electric Generators

The small, dispersed solar electric generators, like wind and residential photovoltaic (PV) systems now being developed, will in most instances require interconnection with the utility to serve as "storage" for any excess output, as well as backup. Utility distribution systems have generally been designed to take advantage of unidirectional flow and diversity of loads. While these small, customer-owned dispersed solar electric generators have the potential for helping the utility meet energy demands, their interconnection with the utility distribution system raises many technical and institutional/economic concerns.

The technical concerns fall in the categories of safety, power quality, and planning and operations. For safety, a technique must be found to assure that these generators will disconnect in the event of a problem on the utility line and remain disconnected while repairs are made. For example, under certain conditions during recent tests at the DOE Southwest Residential Photovoltaic Experiment Station, systems continued to operate after losing the grid signal.

Most of these small generators do not produce power readily acceptable for use on the grid. For example, PV and many wind devices generate a dc power that must be converted to ac power. Usually a solid-state electronic device, called an "inverter," is used to "condition" the power, that is, to change dc to ac, and match voltage and frequency with the utility grid. Although there are inverter designs that can do a good job of conditioning this power, small, lower-cost ones have been known to produce poor power quality.

The two main issues of power quality are excessive levels of harmonic generation and reactive power requirements that can damage customer appliances and utility equipment, and waste energy and money. The magnitude of these two issues are a function of the quality of the inverter employed, and hence likely its cost. On one early grid-connected PV residence using a relatively simple, low-cost inverter, the current harmonic content has ranged from 13 to 50 percent, depending on the time of day and the load. The average lagging power factor has been 0.45, with the maximum measured during the day being 0.60. Since on most utility grids the harmonic content is typically only a few percent and the power factor is usually greater than 0.90, these conditions created by the more simple power conditioners are probably unacceptable to most utilities on a routine basis.

Voltage regulation, system sizing, stability, load management potential, system protection, and new utility planning models are some planning and operational issues to be addressed. In general, adequate and appropriate information is not available.

Most of these technical issues have identifiable hardware solutions, but cost limitations compound the problem.

Of the institutional/economic concerns, rates are probably the greatest issue. The law (PURPA) requires the utilities to interconnect with customer-owned generation systems and pay the avoided costs for the energy fed to the grid. Yet the other utility customers cannot be subjected to reduced power quality or extra costs. Items that must be considered in these rates are costs of backup and utility system modifications, and the values of energy displacement and capacity credit, the last item being the extent to which the solar generator can displace conventional power plants. Of these items, capacity credit will probably be the most difficult to define . . . and achieve.

The capacity credit is a function of the solar availability, the mechanical reliability and how well the power output profile matches that of the utility customers' demands. For a customer-owned installation, the credit will also depend on how quickly a broken system is repaired.

Mechanical reliability will probably be statistically high. Solar availability, however, will vary greatly according to locale. Typically, PV generators will exhibit a sharp peak in production near noon. For utilities having a load demand curve that nearly tracks the sun, capacity credits might be relatively high in sunny climates. For utilities with early morning or late afternoon peaks, the capacity credits will probably be quite low. For example, a solar plant that produces 10 kilowatts (kW) of power at noon on a sunny day, might only be credited with a fraction of this amount, say 2 to 5 kW, as a reliable generator on the system. Without storage, the capacity credit might even be zero, meaning that the solar plant is only a fuel saver, and not a reliable contributor to the utility's ability to meet the demand.

The early installations probably will have little or no capacity credit because their performance will not be known, and they will not displace existing facilities or even new facilities until the aggregate generation capacity of these small, dispersed power producers becomes large enough. The capacity credit for later, better characterized systems will be a function of the degree of penetration and will vary from utility to utility. Without long-term storage, however, it seems to be generally accepted that after some optimum degree of penetration each additional increment will have a smaller capacity credit, eventually reaching zero.

In most instances, the information required to resolve the concerns raised by the use of small, dispersed solar power producers on the distribution system is not available. Applicable criteria for power quality and safety do not exist. The behaviors and impacts on the grid are not sufficiently characterized to allow grid system design, and to predict costs and energy values. Modeling development, experiments, and hardware demonstration are required before small, dispersed solar electric generators can be widely and wisely deployed on the grid.

## On-Site Summary

On some utility systems, especially those using mostly oil, on-site solar has value as a fuel saver. The benefit of on-site solar can be substantially extended to more utilities if the solar application serves to reduce or help meet peak demands. To obtain this benefit, however, the solar system must be properly designed for that purpose. A "proper design" is going to vary by region and utility, and storage will probably be a crucial factor. Some applications might not have a proper design for a given situation, and some innocent-looking on-site solar systems could even be an economic detriment to the utility, its customers, and/or the owners of the solar devices.

## Central Station

The central station conversion of solar energy to electricity, and possibly transportable fuels, represents a large potential application for solar energy. There basically are two choices for converting sunlight to electricity: photovoltaics and thermal. Although their mechanisms are different, they have some common characteristics. Again, the variability of the solar source and its low power density raises technical and economic difficulties. When and if today's developing solar-electric technologies become economically viable, the need for conventional plants for the night and during extended cloudy periods will limit solar power plant penetration to some fraction of the total generating capacity. One solution is to develop economical, long-term energy storage devices, but this development may not happen within our lifetimes.

Although it cannot soon replace dependence on coal and nuclear, especially that used for baseload, solar-electric generation does represent a possible alternative to expensive oil-fired generation and possibly some coal-fired generation used to meet peaking and intermediate loads, respectively.

## Central Station Photovoltaics

Compared to distributed roof-top PV, central station PV represents a more traditional approach for the utilities. It shares some of the advantages of on-site PV plus resolves some of the problems.

Some inherent features of any PV system result in cost advantages. Once the capital investment is justified and made, the fuel is free and inflation-proof. Because of simplicity and modularity, PV plants can be built quickly and in sections with each section perhaps producing power as added. This aspect should reduce the cost of interest on money used for construction, relative to most conventional plants.

PV, as a utility would use them, appear to be essentially environmentally benign, as they are quiet, clean, and have minimal waste problems. Hence, they will probably be well accepted by the public and easily licensed. Although there is some economy of scale to PV systems, the optimum size compared to conventional utility plants will presumably be fairly small, in the 10 to 100 megawatt (MW) range. These factors give PV power plants great siting flexibility including siting near the load. For many parts of the nation the lack of a need for cooling water for most PV system designs is an added siting advantage.

PV plants will probably be easy to operate. Startup power and time requirements are small. Most installations will probably be automatic, requiring little, if any, on-site supervision.

There are some advantages unique to central station PV power plants compared to on-site applications.

One advantage already mentioned is economy of scale. Generally for the same power quality, the larger inverters have a lower unit cost than the smaller ones. This aspect is true for other non-area-related items.

Similarly, there is economy of scale in marketing. By dealing with only a few hundred utilities, the same degree of sales and installed capacity can be achieved as by dealing with tens of thousands of homeowners. This aspect could have a significant impact on cost, and ultimate penetration of PV could occur much more quickly with central station than with smaller installations.

What will probably prove to be the most important advantage of central station PV, compared to distributed systems, is the ease of utility grid interfacing. Because of its size, the central station plant can be integrated into the transmission system in the traditional manner. The utility has control in determining the operation of the system and the quality of the power. The size, operating characteristics, and dispatching can be optimized with respect to the other generation on the grid and the load. Safety is much more readily achieved and assured. In short, most of the potential problems of interfacing small, dispersed PV systems with the grid disappear or are more easily resolved in the bigger central station applications.

PV systems, of course, have their drawbacks. Capital cost is a main one. The projected prices for these systems are generally cost competitive only with the higher priced fuels, such as oil. This fact naturally limits the penetration of PV, the degree being a function of the particular utility. As discussed earlier, even more restrictive are the limits to capacity credit caused mainly by the uncertainty of the availability of the sun and how closely the PV output matches the load. At one extreme, for utilities using a high percentage of oil, exhibiting a demand profile that closely follows the sun, and having adequate solar resource, PV could result in significant fuel cost savings and capacity credit. At the other extreme, utilities where oil usage is low and the demand does not match the sun, PV would have a more limited penetration, mostly as a fuel saver with little to no capacity credit.

Storage would enhance the value of PV, but unlike solar thermal electric that can sometimes use thermal storage to an advantage, PV would be in competition with conventional electric generation for charging "electric" storage, if it becomes economical.

From a national utility perspective, large contributions to our energy supply by using PV will require PV to compete economically with coal-fired power plants. To achieve this position, not only must the cost be reduced, but the efficiency of the solar cells will probably have to be increased by about a factor of two over today's technology.

Although some advantageous operational features exist for PV, dependency on availability of the sun might result in some system stability and dispatching problems. Again, storage, if economical, would be helpful.

Because of simplicity, lack of moving parts and use of solid state components, a rather long life would be expected, although degradation of performance with time is an uncertainty. The federal programs' goals anticipate a twenty-year life, which is short by utility standards.

Although not a problem for roof-top applications, land requirements for a significant deployment of central station PV might be excessive.

For utilities to be comfortable with purchasing large quantities of PV, a responsive supplier base will have to be established. Many of the current PV suppliers have not traditionally dealt with utilities and this lack of familiarity may pose a stumbling block.

There are a number of items that appear to be of no concern with central station PV, but must be demonstrated to remove uncertainty: safety, grid interface, plant availability independent of solar availability, load following capability, and so on.

## Photovoltaic Systems

At present photovoltaic solar collector systems fall into two major categories: flat plate and concentrating. In flat plate arrays, solar cells cover almost the entire area exposed to the sun and the modules are typically positioned in a fixed southerly direction. Since flat plate modules operate on both direct and diffuse sunlight, they have almost universal geographical application. They can be deployed in a wide range of sizes from roof-top to central station.

In concentrating systems, such as the one used in the DOE/Arizona Public Service Company (APS) Sky Harbor Airport Solar Project, some form of optics such as the Fresnel lens or a concentrating mirror is used to concentrate the sunlight onto a concentrator-type solar cell. These systems presently using silicon solar cells have concentration ratios in the range from ten to a few hundred times. Less common are high concentration systems using ratios above a thousand suns. In general, the efficiency of the solar cell increases as the concentration is increased, provided the cell is kept cool. Since concentrating systems can only use the direct component of the sunlight, they must incorporate a structure to track the sun, and will probably be limited to the sunnier regions for the early commercial deployments. The complexity of the tracking structure will probably limit applications to nonresidential. The advantage of concentrator systems is that they use considerably fewer solar cells to produce the same power as a larger number of solar cells used in a flat plate arrangement. The reduction in cell area is proportional to the concentration ratio. To be cost effective, the savings of using fewer cells must exceed the added cost of tracking and concentration hardware.

Although much R&D has been performed on PV systems, a specific uncertainty that remains is the optimum design(s) and cost of the balance of systems, i.e., the non-solar cell items of the plant. This situation is particularly true for flat plate configurations. Most of the cost-reduction efforts to date have been spent on developing a low-cost solar cell array. More effort, involving utility input, is required in developing low-cost balance of systems. Furthermore, the array and balance of system should be optimized together. Failure to do so could be an economic show stopper.

## PV Summary

Before utilities will buy any significant amounts of PV, system hardware must first be adequately developed and demonstrated, a reliable and capable vendor industry must exist, and of course the cost must come down. Current cost projections are based on economic competitiveness with oil, and later gas, fired generation. The contribution to generation by these fuels, however, is expected to drop from 25% to 13% by 1990, according to the 1981 report of the National Electric Reliability Council. Significant penetration of PV from a national utility point of view is unlikely unless PV can compete with coal. To do this will probably require an almost doubling of solar cell efficiencies to over 20%. On the other hand, the projected market for current solar cell technology is still large from the point of view of a PV supplier.

## Solar Thermal Electric

For some utilities, the process of converting sunlight into thermal energy before conversion into electricity holds the promise of a greater penetration of the generation mix than does photovoltaics. A fluid, heated in a solar collector, such as a flat plate or solar pond, or a trough or bowl mirror concentrator, is then converted to electricity in turbomachinery, much as in a conventional power plant. In general, the economics improve as the efficiency increases, efficiency increases at higher temperatures, and higher temperatures are produced by concentration of sunlight. Thus, trough and especially bowl concentrators have created the most interest.

One "bowl" concentrator, the central receiver, appears at present to have the edge in achieving a commercial status for utilities. This concept heats a fluid in a receiver atop a tall tower, hundreds of feet high, surrounded by a field of thousands of tracking mirrors, called heliostats, that reflect sunlight to the top of the tower. These mirrors are about twenty feet on a side. Concentrations of over a thousand suns are typical for this concept. The heated fluid is used in turbomachinery, like steam and gas turbines, to produce electricity. An inherent advantage of most solar thermal systems is that the collected thermal energy can also be stored for later use, or a fossil-fired backup can be relatively easily integrated into the plant.

Several central receiver design options have been developed, characterized for the most part by their heat transfer fluids: water/steam, molten salt, liquid sodium, air, and helium. The selection of transfer fluid influences the receiver design, the thermodynamic cycle, and the mode of storage, if used. In the water/steam and gas concepts the fluid can be conveyed directly through the steam or gas turbine, respectively. In the molten salt and sodium systems the hot fluid is used to produce steam in a steam generator ahead of the turbine.

The water/steam central receiver option will be demonstrated first by operation in 1982 of the 10-MWe Barstow Pilot Plant, called Solar One. This plant represents first generation solar thermal technology. It is not representative of plant efficiencies that can be obtained using present day steam turbine technology and is not considered to be a demonstration of a cost-effective system. Solar One, however, will provide the valuable function of showing that the central receiver system is a viable operating system, and that all subsystems (collector-receiver, storage and controls, etc.) can operate as an integrated system with the electric power generating subsystem (turbine-generator, condenser, pumps, etc.).

Of more ultimate significance to utilities are the advanced technologies, which offer the promise of higher efficiencies, possibly low-cost thermal storage, and cost reductions. Current near-term application efforts are being concentrated on the use of advanced water/steam, molten salt, and liquid sodium systems for solar repowering. In solar repowering, a solar thermal plant is placed adjacent to an existing oil/gas fired plant and used to generate steam for the existing plant's turbine when energy from solar is available, thus displacing oil and natural gas.

In 1978, Public Service Company of New Mexico, under contract to the Department of Energy, conducted the first significant technical and economic assessment of repowering to determine the potential for solar repowering. The resulting market survey indicated that at a 50 percent repowering level, the potential market in the southwest U.S. would be approximately 5000 MWe.

In addition to the potentially large market, the repowering arrangement provides what is probably the cheapest R&D approach to developing the solar central receiver technology. The construction of one or more 50 to 100 MWe solar facilities at existing oil/natural gas fired power plants, such as the facility we are designing for our Saguaro Power Plant, would not only demonstrate repowering, but stand-alone solar plants as well. Such tests would prove advanced components, stimulate industrial production, and give the utilities much needed data for making planning decisions about the utilization of solar power plants.

The single most costly item of a solar central receiver power plant is the heliostat field, estimated to be over 50 percent of the total plant cost if built today. The heliostat also represents the greatest opportunity for cost reduction, and projections indicate that the cost can be reduced to represent about a third of the plant cost. This reduced cost level can probably be achieved at an annual heliostat production of about 50,000. At this level, depending on the utility and its location, a solar central receiver power plant should compete with oil-fired generation, and perhaps coal-fired generation used in an intermediate mode. Since a 100 MWe solar plant uses about 10,000 to 20,000 heliostats, not very many experimental and near commercial lead plants would be required in order to reach a 50,000 heliostat annual production level.

Solar thermal central receiver power plant concepts offer to varying degrees the prospect of reasonably priced energy storage in the form of thermal energy. For utilities where the daily load curve does not match the sun's and that do not use large quantities of oil, the use of storage can greatly enhance that value of the solar plant by maximizing the displacement of oil and gas. Storage also acts as a buffer to protect the turbine-generator from solar transients. In this situation, steam for the turbine is created in a steam generator "fired" by energy taken from the storage charged by the energy collected in the solar receiver.

Of the advanced concepts, molten salt probably offers the lowest cost storage for greater than three or four hours by using the same molten salt transfer fluid as the storage medium. Sodium can do likewise, but storage capacity is limited to something probably less than an hour because of the high cost of sodium. Water/steam systems normally use the steam directly out of the receiver to the turbine. If storage is utilized, it is probably oil and rock. In water/steam system storage, a temperature drop occurs, resulting in a 30 percent reduction in efficiency. Any of these systems could probably incorporate molten salt storage by using heat exchangers.

It is not clear which of the advanced concepts will ultimately be chosen. Molten salt and sodium offer the capability of using present day, high efficiency steam turbines. APS and some other utilities have chosen molten salt because of its storage potential, the benign nature of the transfer fluid, and relatively low total plant cost projections. Some utilities have picked sodium because of the prospects of a smaller, more efficient and lower cost solar receiver atop the tower. Some other utilities are favoring the water/steam system, at least for initial plants, because they have more confidence in the more familiar steam components.

A more advanced central receiver is being developed by the utilities, through the Electric Power Research Institute. The transfer fluid is air that is heated to a high temperature and expanded through a gas turbine, either open or closed cycle. The higher temperatures result in higher efficiencies, and the use of a gas turbine results in more compact turbomachinery and allows dry cooling, a plus in desert locations. The high temperature receiver is the major development item of this concept. Because of the use of air, a fossil-backup combustor for the turbine is easily integrated into this system and will probably be more cost effective than storage.

## Solar Thermal Electric Summary

Partly because of its inherent ability to incorporate thermal energy storage or hybrid fossil operation, the solar thermal electric central receiver appears to be a viable concept to a significant number of U.S. utilities. Depending on the magnitude of the development program, this generation option could probably be economically competitive with oil-fired generation on many utility systems by 1990, and competitive with some coal-fired generation used in intermediate modes soon thereafter. This option will not be available soon, if at all, if there is not a concerted effort by utilities, manufacturers and government to develop components and demonstrate significant-sized tests. The greatest uncertainty in predicting the ultimate commercial cost resides in the success of mass production in bringing down the cost of heliostats and in the actual efficiency of the collection and conversion of sunlight into electricity.

## CONCLUDING SUMMARY

Not all solar applications have been adequately addressed here, especially some of the transition forms such as wind, biomass and ocean thermal electric conversion. However, much that has been said about solar here is generic. Whether the "grid-connected" solar application is customer-owned on-site or utility-owned central station, economic viability depends on the value of fuel displaced and on its ability to help meet the peak and intermediate demands.

Certain on-site solar applications, if properly designed, appear to offer the possibility of serving as energy saving, load management tools that help to reduce or smooth peak electric energy demands. Utilities are investigating and in some instances encouraging the use of some of these applications that, by reducing the peak demand and saving energy, result in potential cost savings to their customers.

Electrical generation by solar represents the potential to utilize solar energy in a versatile and significant manner. Photovoltaics may become low enough in cost to permit their use in a wide geographic deployment as fuel-saver power plants that are clean and quiet, and can be built in small-sized power increments. The central receiver solar thermal electric power plant, mainly because of inherent storage capabilities, shows great potential for becoming cost competitive as a significant electric generating plant displacing oil and gas and perhaps some intermediate-load coal for many utilities.

In general, it appears that some form of solar energy is or will be able to help meet some of our energy needs. It is important to remember that solar energy appears in many forms and economic viability is determined on a very local basis, depending on the solar resource availability and its quantity and quality, the application, the climate, the style of living and working, the availability and price of other energy sources, laws and regulations, the load demand profile and generation mix of the utilities, and the cost of the solar hardware.

BROWN, MERWIN L., Ph.D.
Manager of Research Programs
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Dr. Brown is a Kansas State University graduate with a B.S. (1966) and a Ph.D. (1973) in nuclear engineering . . . while a student, was a part-time classroom instructor, computer programmer, and textbook editor; in 1971 joined Arizona Public Service Company as Sr. Research Analyst and became Manager of Research Programs in 1976 . . . present duties are to manage the department in the creation and implementation of R&D programs and projects for new energy technologies for APS . . . R&D areas are solar, nuclear, geothermal, coal, energy storage and transport, and electric vehicles . . . some major projects are the 225 kW Sky Harbor Airport Solar Photovoltaic Power Plant, the 60 MW Saguaro Solar Repowering Project, the DOE Electric Vehicle Demonstration, the 13-ton SOLERAS Solar Rankine Cooling/Cogenerating Demonstration, the 15-ton PVNGS Solar Absorption Air Conditioner, and the Yuma Residential Photovoltaic Retrofit . . . memberships include the International Solar Energy Society, American Nuclear Society, Sigma Xi, American Association for the Advancement of Science, Institute of Electric and Electronic Engineers, and Solar Energy Industries Association . . . appointed as a Commissioner on the Arizona Solar Energy Commission and serves on the Arizona DOT Transportation Planning Research Advisory Committee; the Electric Power Research Institute (EPRI) Advanced Power Systems Divisional Committee; EPRI Fusion Program Committee; DOE Southwest Residential Photovoltaic Test Facility Consulting Committee; Gas-Cooled Reactor Associates Technical Advisory Committee, and WEST Associates Energy Task Force . . . lectured and published in the fields of solar and nuclear energy, energy technology R&D, and nuclear fuel management.

Mr. FUQUA. Thank you very much, Dr. Brown.

Dr. Hildebrandt, you and Dr. Brown mentioned the inability of the utilities primarily to fund large-scale demonstration facilities, such as Barstow, by themselves. Would it not even be possible through EPRI to fund large-scale projects of that type?

Dr. HILDEBRANDT. No. Their budgets are too small for that kind of operation. They have participated somewhat in use of the data at Barstow but could not fund significantly. If they were to do a project, it would have had to be a much smaller scale than Barstow, and the utilities are actually needing even larger components.

Mr. FUQUA. Right. Well, I think Dr. Brown mentioned that that was still not a commercial size operation, if I am correct.

Dr. BROWN. Yes; that is right. It is not.

Mr. FUQUA. Dr. Brown, you mentioned, on page 9 of your statement, that the figure for the 60-megawatt repowering plant is considerably lower than that that we were given last year. I don't remember what that figure was exactly, but I think it was higher than that. You quoted $145 million.

Dr. BROWN. Yes.

Mr. FUQUA. What makes you think that it can be built for lower cost or even that there would be a 50-percent utility cost sharing that could be achieved?

Dr. BROWN. There are a number of questions inherent in that one question.

I am not sure which number you refer to that might have been presented last year. First, the $145 million is based upon the work that we just completed last summer on a conceptual design, and this was the capital cost that came out of that particular study.

There is a possibility that the number you saw was stated in other-year dollars. This particular one is stated in 1983 dollars; inflation has not been added. That could explain the differences, because we indeed come up with different numbers depending on what inflation rates we pick.

It was safest to pick a constant dollar for this testimony, and then people can apply their own escalation factors to come up with what real cash flows would be in the out years.

In answer to the other question, in the written testimony, I made reference to the fact that, as a fuel saver, this particular repowering application, if it were to save all oil on a utility's system, our calculations show that it might have a value of roughly 50 percent of the cost of the facility in 1983 dollars. I have to add the note of caution, though, that this is an upper bound of the potential cost sharing.

Things that affect it, of course, are the future price of oil and, indeed, how much oil is really saved by this facility. Then a very important factor is again the utility's perception of the uncertainty and the risk that would go into its portion of the investment of the demonstration.

So the actual cost sharing would depend a lot upon the specific utility, its situation and how it perceived the value of the facility. It could be anywhere from zero, which is probably not a likely successful form of cost sharing, up to around 50 percent, theoretically.

Mr. FUQUA. Mr. Shine, in Dr. Brown's testimony he discussed the parabolic dish. It does not seem to be as attractive to utilities as central receivers because of the lack of storage and also the potential for high maintenance costs and a large number of small components. Could you comment on those observations?

Mr. SHINE. I would not agree with the statement that it has the potential for high maintenance costs vis-a-vis a central receiver system.

I would say that in looking at what the potential market for these systems might be, or the markets for these systems, we have come to the conclusion, and I believe that the Jet Propulsion Laboratory, in one of the studies that they conducted, maybe 4 years ago, on potential markets for parabolic dish systems, that the first and most significant market would be remote site applications; i.e., sites where one of five or six units might be required to generate from 20 to 100 or 120 kilowatts.

The economics of remote sites are entirely different from utility power stations. It does look like the initial dish market would be remote sites for specific small power users. Utilities, as you well know, typically speak in terms of 10's if not 100's of megawatts. Dish modules, in today's technology and the projected technology, will generate about 25 kilowatts maximum per module. It does not make a lot of sense to talk about multihundred modules to produce megawatts, at least at present.

The economics are different. You are comparing apples and oranges, really, but we do not believe, on the maintenance issue, that dishes will be any more difficult to maintain than central receiver units.

On the contrary, if you want to do an analysis, a reliability and maintainability analysis, and you look at a six-unit system, you can speak in terms of having 80 percent or 83 percent capacity when one unit is down. The likelihood of more than one unit being out at any given time is not very great. You have modularity in terms of components and in terms of power production. When a central receiver unit is down the entire system is down; i.e., no power generated.

So again, the dish market, at least initially, appears to be site-specific and application-specific; this is a feature of the parabolic dish systems.

Mr. FUQUA. Dr. Hildebrandt, could Barstow be used as a test facility for advanced receiver and advanced storage and steam generator systems?

Dr. HILDEBRANDT. I think there was a plan to consider a second tower, to look at a sodium receiver at one point. I think that there are some follow-on plans that were developed previously to use Barstow for some additional component testing.

Again, the kind of thing that I see is necessary, for instance, in a salt receiver, say, is that you need to test the fluid behavior, you need to test a section of a receiver, and you need to test storage component behavior. The heliostats are sufficient to do that at Barstow, to test a fraction of a 100-megawatt receiver-boiler system; these systems are highly modular and repetitive. So I think some of those tests could be done at Barstow. However the utility and manufacturer's view is to operate in the present mode for a number of years.

Mr. Fuqua. How expensive would it be?

Dr. Hildebrandt. Well, I think that, for instance, the boiler-receiver tests, the specific component tests, are like in the $10 million to $15 million range that has been proposed by STEA in the 1983 budget. I don't know what the utility view would be on whether there would be an additional systems test required, but I think these component tests are like $10 million to $15 million type projects. They are not redoing Barstow, by any means. Barstow is an expensive project, first of its kind. However, some additional heat transport components would be required to conduct receiver tests at Barstow.

Mr. Fuqua. Let me again thank you gentlemen for coming. We may also have some written questions to submit to you. I apologize for the inconvenience of the interruptions that we have had, but I do appreciate very much your being here and taking your time to share with us your thoughts on a subject that we are very interested in. We also think that these technologies have great promise for solving some of our alternative energy needs in the future.

Thank you very much.

Dr. Hildebrandt. Thank you for the invitation. Thank you, Mr. Chairman.

Mr. Fuqua. The subcommittee stands in recess.

[Whereupon, at 4:14 p.m., the subcommittee recessed, to reconvene at the call of the Chair.]

# APPENDIX I

## Questions and Answers for the Record

DR. A. M. HUBBARD - SOLAR ENERGY RESEARCH INSTITUTE

ANSWERS TO THE QUESTIONS OF

THE MAJORITY COMMITTEE ON SCIENCE AND TECHNOLOGY

1. Please describe the reorganization and redirection you carried out to make SERI conform more closely to Administration guidelines for Federal RD&D.

SERI's mission has been redirected in the Summer of 1981 as a result of the revised Administration guidelines for Federal RD&D. The new mission, which was agreed upon by DOE and Midwest Research Institute, SERI's parent organization, designated SERI as the "primary Federal laboratory for solar energy research." This redirection brought about major changes in program emphasis and staff. Specifically, SERI's research work now emphasizes high-risk, potentially high-payoff R&D in the areas of (a) solar electric conversion, (b) solar fuels and chemicals, and (c) solar thermal and materials. Activities not in support of this new mission and the above research areas were phased out or transferred to other national laboratories, and staff supporting these activities were terminated. In addition, SERI has been reorganized to better focus on solar R&D. SERI's three main research areas have been transformed into three research divisions, which are supported by a financial management division, a procurement and administrative services division, and a human resources office. In addition, SERI has retained its technical information functions as they support the needs of its research divisions.

The redirection and reorganization were completed early this year. The net result, I think, is a leaner, well-focused organization which is determined to accomplish its mission effectively and efficiently.

2. Currently, SERI performs much of its research in rented space. Does that present any problems to your research staff? What would it cost to build a permanent laboratory facility to house your research staff and equipment?

Our research activities in leased space pose no major problems to our research staff. But, while we are performing quality research in our present quarters, we pay a penalty in operating costs and efficiency. Over the long term, permanent research laboratories would be more cost effective and enhance the accomplishment of SERI's mission. Consistent with this, I am happy to inform you that on June 21 of this year a contract was signed for the construction of a field test laboratory building. It is SERI's first permanent building and will be a multi-purpose research building with facilities for thermochemical conversion, biotechnology research and hybrid energy systems. It will accommodate approximately twenty percent of our present research staff.

Our planning calls for modular development of SERI's permanent site as economic circumstances and the federal budget permit. The next building would be a research laboratory building which would complement the Field Test Laboratory Building currently under construction and would house the bulk of our present research staff. The estimated cost for this permanent laboratory facility which will house most of our research staff and equipment is $25 million.

3. We have heard a lot about amorphous silicon photovoltaics devices this year. Do you believe that is going to be the "winner" among the thin film materials? Should DOE concentrate all of its advanced R&D funds on amorphous silicon?

Recently there have been some rather spectacular improvements in material quality and device behavior in the amorphous silicon area. RCA Laboratories, performing photovoltaic research cost-shared with SERI, has announced (July 22) the operation of an amorphous silicon solar cell at a record high 10% efficiency. The 10% efficient cell represents the achievement of a major milestone in the National Photovoltaic Advanced Research and Development Program. Others (e.g., ECD, Inc., and several Japanese organizations) have reported cells with over 8% efficiency. All of these cells have an area of approximately 1 $cm^2$ or less. Large area cells (greater than 100 $cm^2$) with efficiencies of 7.0% have also been reported by the Japanese. Single junction amorphous silicon devices are eventually expected to reach laboratory efficiencies of 13% and module or large area efficiencies of 11%.

Although there have been dramatic advances in the amorphous silicon program managed by SERI, there are problems which require further research. High efficiency devices exhibit light induced changes in performance parameters. Present material deposition rates are too slow for practical, large scale use and various deposition techniques do not produce materials with consistent device capability. Consequently, research is needed on large area cells to study material uniformity, reduction in defect density, low temperature metallization, and encapsulation. Also, various interface interactions between material layers in the cell and impurity effects are poorly understood and thought to inhibit ultimate cell performance and cause cell degradation.

Finally, no good theoretical base exists from which to predict future directions. Other related high-potential areas include investigation of amorphous silicon alloys which can be utilized in multijunction amorphous cells (these multijunction devices have estimated efficiencies of over 20%) and other amorphous materials possessing a more optimal bandgap for solar conversion.

In summary, we do believe, based on empirical developments, that amorphous silicon is going to be one of the winners. There is, however, much work to be done on amorphous silicon and other material areas which are promising (e.g., copper indium diselenide, multijunction concentrators based on gallium arsenide, advanced silicon ribbon and others). Ultimately there will probably be several winners because of both the unique requirements of various applications and the fact that commercial competition in the U.S. has often led technical ingenuity to produce multiple solutions to a single problem. We believe that to concentrate all R&D funds on a single area now would be at best premature and possibly unwise in the long term.

4. What should be the respective roles of SERI, JPL and Sandia in solar energy over the next few years? Should SERI become the only national laboratory for solar RD&D?

Ideally, the roles of SERI, JPL, and Sandia in solar energy research should be complementary. Presently, SERI's efforts are focused primarily on exploratory and applied research, whereas JPL concentrates on engineering and systems development, and Sandia on engineering hardware.

However, as Federal R&D budgets have become smaller and their focus has shifted to long-range exploratory research, some centralization of programs in the next few years may be necessary. The alternative would be an "across the board" reduction of each laboratory's already small budget, and the attendant loss of the "critical mass" necessary to do a good job at any one of them.

Because SERI has been assigned the mission "to be the Nation's primary laboratory for solar energy research" and to conduct and coordinate long-term, high-risk solar R&D projects, I think that placing and continuing the primary responsibility for such solar R&D programs at SERI will increase the efficiency of these R&D programs.

5. You have had some striking successes with new materials such as copper indium diselenide and with multi-layer cells. Can you tell us about that?

Thin-film cadmium sulfide/copper sulfide solar cells have been under development for more than 20 years, and have recently achieved AM1 efficiencies of the order of 10%. Serious stability problems, however, have plagued successful development of commercial devices. In an effort to achieve efficiencies exceeding 10% in stable thin film cells with cadmium sulfide in conjunction with a different light absorber, DOE started funding promising research at Boeing Aerospace on thin-film cadmium sulfide/copper indium diselenide structures in 1977. This action was based on the fact that copper indium diselenide was (and still is) one of the most optically absorbing semiconductors known. In addition, S. Wagner had demonstrated 12% efficiency in devices made on single crystal copper indium diselenide in 1974, and Larry Kazmerski, presently with SERI, had deposited thin-film cells with efficiency of approximately 6% in 1976.

In 1978, SERI assumed responsibility for the Photovoltaics Advanced Research and Development Program and continued to fund the DOE-initiated work at Boeing. This research has made significant progress during the past four years. Boeing has just reported achievement of another milestone in the (cadmium, zinc) sulfide/copper indium diselenide thin-film solar cell program. Using copper indium diselenide vacuum evaporated from the elements, a 1 $cm^2$ thin-film cell was deposited with a reported efficiency of 10.6%. This efficiency represents the highest efficiency reported to date for any polycrystalline thin-film compound semiconductor.

Boeing has made progress in the compositional control of the copper indium diselenide and in the deposition of copper indium diselenide in a planetary (rotating) evaporator. The planetary evaporator allows the deposition of a large number of cells at one time and is the first step toward a lower cost process. Preliminary indications from stability testing in copper indium diselenide are also very promising. No degradation in any of the photovoltaic characteristics of unencapsulated cadmium sulfide/copper indium diselenide cells has been detected during the first 7,500 hours of constant simulated AM1 illumination testing at temperatures up to 80°C. These cells were kept in the Seattle environment during testing.

In addition to continuation of the research at Boeing, the current thrusts of the SERI copper indium diselenide program are studies in large-area deposition, principally by sputtering, annealing studies including characterization of an unanticipated and undesirable diode junction at the cell back contact recently discovered at SERI, first-principles band-structure calculations on copper indium diselenide and related ternary chalcopyrites, and single crystal studies aimed at increasing the open-circuit voltage in the thin-film devices.

The cadmium sulfide/copper indium diselenide results represent the first truly thin-film cell that is stable over a long period with an efficiency of greater than 10%. Further research could lead to higher efficiency and a much lower cost than present silicon cells. This would allow for rapid expansion of photovoltaics into new applications.

The multilayer solar cell is an approach which has the potential for providing photovoltaic conversion with more than 30% efficiency. The concept has received approximately five years of research. This effort has been directed towards improving the understanding and quality of compound semiconductors such as Aluminum Gallium Indium Arsenide (AlGaInAs), Aluminum Gallium Arsenide Antimonide (AlGaAsSb), and Gallium Arsenide Phosphide (GaAsP). These material systems were selected based on the knowledge that appropriate crystal structures, electronic, and optical properties might be simultaneously achieved as needed for the multilayer cell.

Prior to 1982, the best multilayer cells demonstrated in the laboratory had achieved efficiencies of approximately 16%. In the past year the performance has reached 22% at a solar concentration level of 130 suns for a GaAlAs on GaAs cell structure. This was the result of discovery of a new concept in design of the cell. The new design replaced two semiconductor layers with metal to form an interconnect between the active solar cell layers.

In order to continue improvement of multilayer cells, research must develop techniques for reducing the density of crystalline defects. Most defects in the active semiconductor layers provide a loss mechanism for photogenerated carriers which reduces the efficiency of the cells. A technique minimizing defect densities has recently been discovered at SERI. This technique uses a series of very thin alternating crystal layers (a superlattice) to build in a controlled strain which prevents the propagation of defects from the substrate into the active solar cell layers. While still in an early stage of research, this unique approach offers considerable promise for achieving the performance potential of multilayer cells.

If the high efficiency potential of these cells is achieved, it will nearly double the efficiency, compared to today, of photovoltaic conversion and significantly reduce the area related costs and total photovoltaic system costs. It will also open up an area of hybrid (solar thermal and solar electric) applications.

6. What budget and staffing levels do you see as needed over the next few years to keep SERI's R&D activities functioning at a healthy level?

Level funding and staff over the next few years would enable us to make solid progress toward achieving SERI's mission. It should be noted, however, that the effective conduct of long-range research to carry out the SERI mission requires multi-year programming and a stable resource base. It is better to maintain a level effort which permits systematic planning than to experience sudden budgetary ups and downs even if such changes provide more funding in the aggregate. Finally, some budget increases could be usefully employed to deepen and widen the scope of our research programs and to achieve healthier progress toward accomplishing our mission to be the primary Federal laboratory for solar energy research and to conduct and coordinate long-term, high-risk research and development on solar technologies.

7. According to your Institutional Plan, you appear to need about $43 million a year to continue existing activities for the DOE solar programs and about $58 million a year to continue existing activities and add new initiatives. Yet according to OMB's Fiscal Guidance, the total solar budget for DOE is likely to dip to $40 million by FY1985. What assurances have you received, if any, about budget and staffing stability from DOE?

The most recent assurance that we have received about budget and staffing stability was included in a recent DOE planning guidance for SERI. This guidance, dated 6/30/82, stated:

> Approximately $40 million is programmed for SERI in FY1982, and the Department intends to provide essentially level funding for the planning period FY1982-FY1987.

In addition, in a testimony before the House Committee on Energy and Commerce on February 24, 1982, the Secretary of the Department of Energy, Dr. James Edwards, stated on page 65 of the Hearings, "In 1983 SERI will spend $40 million", and that it should, therefore, expect level funding.

Based on these assurances we are planning our SERI research activities assuming level funding and staffing. We believe that this level will enable us to make meaningful progress toward achieving our mission.

8. What level of effort do you believe is required over the next few years to maintain an adequate advanced research and development program for photovoltaics?

The question is a difficult one to answer unless one clearly defines what is included in advanced research and development. If I limit the question to what level of effort is required for an adequate photovoltaics advanced research and development program that is managed by SERI (i.e., in-house and subcontracted), then a level of approximately $18 million would maintain a minimum base program. This would allow the continuation of the FY82 programs which emphasized thin film materials (amorphous materials, copper sulfide/cadmium indium selenide, gallium arsenide, etc.), new forms of sheet silicon and some work on electrochemical photovoltaic cells and advanced concentrator concepts. If an enhanced program which would include increased funding for electrochemical and high efficiency multijunction advanced concentrator cells and provide for new initiatives and new materials investigation were desired, then a budget of $25 - $30 million would be needed.

9. Do you believe the current (FY1982) photovoltaics program is properly balanced between advanced research, technology development and systems R&D?

I believe that given the transition from a more applications-oriented program to an R&D program, the balance of the FY1982 photovoltaics program is reasonable. It provides for a minimum advanced research and development budget at SERI, an adequate technology development effort on flat plate silicon and concentrators, some systems R&D and the completion and collection of information on important proof-of-concept experiments. For FY1983 and beyond, as the technology development, systems, and experiments are phased down or out, I would expect that a larger fraction of the photovoltaics budget would be allocated to advanced R&D.

DR. A.M. HUBBARD - SOLAR ENERGY RESEARCH INSTITUTE

## ANSWERS TO QUESTIONS OF THE MINORITY COMMITTEE ON SCIENCE AND TECHNOLOGY

1. In your testimony, you point out that SERI's mission has now been redirected to focus in on long-term, high-risk R&D. We applaud this change. In accomplishing your tasks, what type of funding level and staffing requirements do you believe will be necessary? Do you believe it will be necessary to construct a permanent building facility or laboratory in order to allow you to carry out your objectives?

I'm glad you approve of the redirection. The SERI and MRI management are comfortable with the change in SERI's mission and feel positive about the Institute's future as a result. The redirection, which emphasized a greater concentration on research and development of solar technologies, involved major changes in program emphasis and reductions in staff. This transition was completed earlier this year.

The successful conduct of long-term research requires stability of staff and resources. It also requires continuity in program planning from one year to the next. The funding level for FY82 was sufficient to allow us to make solid progress in a number of our research areas, and supported our continuing efforts to achieve the stability and maturity required of an outstanding research and development laboratory. I feel that a funding level of approximately $45 million for FY83 is appropriate for our needs. This is about the same level of funding as received for FY82. The Department of Energy recently advised us to plan our FY83 work assuming level funding.

Currently our research activities and administrative support services are conducted in leased quarters. These facilities are more than adequate to accommodate our administrative service functions but they are not well suited for our research activities. While we are performing quality research in our present quarters, we pay a penalty in operating costs and efficiency. Over the long term, permanent research laboratories would be more cost effective and enhance the accomplishment of SERI's mission. Consistent with this, I am happy to inform you that on June 21 of this year a contract was signed for the construction of a field test laboratory building. It is SERI's first permanent building and will be a multi-purpose research building with facilities for thermochemical conversion, biotechnology research and hybrid energy systems. It will accommodate approximately twenty percent of our present research staff.

Our planning calls for modular development of SERI's permanent site as economic circumstances and the federal budget permit. The next building would be a research laboratory building which will complement the Field Test Laboratory Building currently under construction and would house the bulk of our present research staff.

2. The Committee has always been concerned about the changes that always seem to take place in administering and managing the DOE renewable programs. How have these changes affected SERI's programs? Do you believe that you have had satisfactory input into the DOE program and policy making activities in the solar area?

The most recent significant change, of course, occurred early in 1981. Consistent with guidance received from the DOE, SERI and Midwest Research Institute, the operator of SERI, concluded that greater concentration on research and development of solar technologies was necessary. High priority areas were to be strengthened. Activities not consistent with SERI's new mission were to be reassigned to other institutions, or terminated if the Department of Energy so chose. We are in agreement with the redirection reflected in SERI's mission statement as recently approved by DOE.

As a Federally funded laboratory, SERI receives and accepts policy guidance from the Department of Energy. There is close, two-way communication between my office and key officials in the Department. We are responsive to the DOE. I will continue to request the guidance and the resources needed to accomplish our mission, and I will continue to make sure DOE managers are aware of SERI's opinions on program issues and priorities.

I view SERI as a research laboratory concerned with providing the scientific and technological base this country needs to utilize its renewable energy resources. As such, we should have a significant role in program planning. However, I do not believe that "policy making" is an appropriate SERI role. That role belongs to the Department and the Congress. The Congress seems to have recognized this relationship when it created SERI. Public Law 93-473, which established SERI, provides that the Institute shall perform research, development, and related activities considered necessary and appropriate by DOE in support of the national solar energy program. If we get involved in "policy making", it should therefore be only as scientific and technical consultants.

3. As I understand it, the content of SERI's research program is dictated by the program offices in the Office of Conservation and Renewable Energy. Does SERI have discretion to undertake promising avenues of research that it identifies itself? Or is SERI merely a job-shop responding to the DOE program directions? You have an impressive team of well-qualified scientists and engineers. To what degree are they able to independently exercise their creativity?

The question you raise is a basic problem not unique to the present situation. When designing a research program, it is always difficult to properly balance the influence of the researchers and the influence of the source of funds. My views on the subject are reflected in a recent statement by Dr. Edward David, President of Exxon Research and Engineering. He said in part:

> We must remember that R&D does not prosper through funding alone; there are values to preserve. Essential are the integrity of the research process, the freedom of academic opinion and expression, and the dominance of excellence. In order to tap the creativity of people, it is necessary to give them a certain freedom of action and leeway to follow their ideas. Otherwise, society cannot take advantage of their talents. On the other hand, the funder, whether it be a corporation, government agency, or limited partnership, must set a framework for evaluating technical activities in relation to its own purposes. (Science, August 13, 1982).

Finding the proper balance between influence of the funder (DOE) and the performer (SERI) is not easy. It requires that there be close cooperation, mutual understanding, and recognition of the roles and legitimate interests of both parties. DOE and SERI are working together toward that goal. Moving from programs which emphasized systems and commercialization to programs emphasizing research and advanced development makes substantial planning involvement by the performer desirable. I believe this is recognized by DOE.

We do have an impressive team of well qualified researchers. Our planning process and the dialogues between SERI and DOE program staff provide mechanisms through which the creativity of our researchers is exercised and often supported.

4. You stated that successful conduct of long-term research requires stability of staff and resources as well as continuity in programming. How would a reduced budget affect your activities? What amount of funding do you feel you require in order to accomplish your mission? What flexibility do you have or would you need in order to do better exploratory research and development? What is the budget level that you would consider adequate for these purposes and how would you spend such funds? What do you feel would be the most promising areas of fundamental and exploratory research?

Any experienced research and development manager will tell you that doing effective long-range research takes time and requires continuous effort. Therefore, multi-year programming and a stable resource base are necessary to high quality research. It is better to maintain a level effort, which permits systematic planning than to experience sudden budgetary ups and downs, even if such changes provide more funding in the aggregate.

As I stated in my answer to your earlier question (see No. 1), a funding level in 1983 equivalent to our 1982 new budget authority of $44.6 million is appropriate to our needs. I am confident this level of activity maintained in the coming five years will enable us to make solid progress toward accomplishing SERI's mission. However, a major reduction in SERI's funding at this stage in its development, considering the fact that our 1982 new budget authority has already been reduced by 60 percent from 1980, would have an unfortunate impact on our staff and would result in a significant decrease in our long-range research capability.

Exactly how a reduction would affect our activities would depend upon the amount of the decrease and the research areas impacted. As you know SERI is not funded as a line item but is allocated funds by the Department according to specific Budgeting and Reporting and program category. A reduction of 10 percent in an overall funding could probably be accommodated without too much damage to SERI as an institution but a reduction beyond that point may present us with a danger of losing "critical mass." Similarly, an increased budget could be usefully employed to deepen and widen the scope of our research programs and accelerate progress.

Flexibility in programming is made possible through the use of two mechanisms. First, and most important is the continuing two-way communication between SERI and DOE program managers, which makes it possible to efficiently adjust ongoing research programs based on findings from current research. Second are the discretionary funds available to the SERI director. We are working with DOE to improve the effectiveness of the first mechanism. This is important because exploratory applied research requires more flexibility than systems development. We are also working to improve SERI's use of discretionary funds available to us. At present, these funds amount to less than one percent of SERI's budget. As our track record continues to improve, I hope that amount will increase. Such funds are normally used as seed money to fund new research ideas, to examine new technical concepts, and to provide initial research funds for new senior research staff.

It is difficult within the limitations of this format to be very definitive concerning the most promising areas for fundamental and exploratory research. We think a balanced program is important. Among current work at SERI I am particularly impressed with the potential for thin-film photovoltaics, advanced research in biotechnology, photochemistry and photosynthesis, and improved solar thermal materials.

5. We are aware that Sandia has responsibilities in hardware development for solar thermal systems. We are also aware that JPL and Sandia play a role in the overall photovoltaic program. Do you feel this is a duplication in these activities and that spreading the major solar programs across several labs may dilute the return on the taxpayer dollar?

I have great respect for the often demonstrated fact that no one institution has a corner on creativity and believe that a certain amount of competition is a good thing in science, just as it is in other areas. However, in my opinion there is no significant duplication in activities among JPL, SERI and Sandia. In large part, the work at these laboratories is complementary and it is my perception that we work together very effectively. SERI's efforts are focused primarily on exploratory and applied research, whereas JPL concentrates on engineering and systems development, and Sandia on engineering hardware.

However, as budgets become smaller and emphasis shifts toward long-range exploratory research, some centralization of programs may become necessary. The alternative would be an "across the board" reduction of each laboratory's budget, and the attendant loss of the "critical mass" necessary to do a good job at any one of them.

Because SERI has been assigned the mission "to be the Nation's primary laboratory for solar energy research" and to conduct and coordinate long-term, high-risk solar R&D projects, I think that placing and continuing the primary responsibility for such solar R&D programs at SERI will increase the efficiency of these R&D programs.

RESPONSES TO WRITTEN QUESTIONS SUBMITTED BY CONGRESSMAN FUQUA DURING THE HEARING BEFORE THE HOUSE SUBCOMMITTEE ON ENERGY DEVELOPMENT AND APPLICATIONS ON JULY 28, 1982, TO DR. M. ALPER/JPL.

QUESTION RE-1

A lot of people feel that silicon photovoltaic cells will never meet the DOE cost goal of 70¢/per peak watt. Do you agree? What do you see as the most promising approaches to meeting the cost goals with silicon?

ANSWER RE-1

JPL has been convinced for almost a decade that crystalline silicon flat-plate collectors can be profitably manufactured and sold at less than 70¢/per peak watt*, given appropriate technological development. Rapid technical progress in silicon photovoltaic technology has reinforced this belief and substantially increased the probability that several approaches to silicon ribbon collectors may have the capability for meeting an even lower target of 50¢/per peak watt. In addition, several approaches to Fresnel lens concentrator collectors with silicon cells show much promise of meeting the 70¢/per peak watt goal.

JPL is supported in this belief by the other national laboratories involved in the photovoltaics program. The Solar Energy Research Institute and JPL recently (Feb. 1982) completed a joint, detailed assessment of 19 advanced silicon flat-plate technologies. In the opinion of JPL and SERI researchers, 11 of these approaches had greater than a 75% probability of meeting a $1.00/per peak watt target, and six had greater than a 50% probability of meeting the 70¢/per peak watt goal (the highest ranked process was found to have a 79% probability of meeting the 70¢/per peak watt target). These same six processes each had greater than 25% probability of meeting 50¢/per peak watt. Sandia has conducted several assessments indicating that both linear Fresnel lens concentrator collectors, such as those whose development Sandia has sponsored at E-Systems, and point-focus Fresnel lens concentrators as exemplified by those manufactured by Martin Marietta, have the potential to meet the 70¢/per peak watt target employing silicon cells.

Almost all present solar cell array manufacturers employ a silicon ingot technology. Most manufacturers feel, as does the Photovoltaic Program, that while silicon ingot technologies still have much potential for cost reduction, achieving 70¢/per peak watt will be difficult. Depending on the cost of silicon feedstock, many ingot technologies, especially the cast ingots, do show promise for approaching this target, however. Some firms believe that no silicon based technology can achieve the necessary cost reductions, and have turned to thin films or other materials as an alternative. Still other firms, believing in the ability of advanced silicon technology to meet or exceed the cost goals, have invested heavily in advanced silicon ingot and silicon ribbon technologies (e.g. Martin-Marietta, Mobil-Tyco, Arthur D. Little, Motorola, Westinghouse, Arco Solar, Solorex).

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*All values quoted are in 1980 dollars

As the SERI/JPL assessment revealed, the most promising opportunity to attain 70¢/per peak watt silicon flat-plate collectors exists with material conservative, thin, wide ribbons of silicon substrate drawn from a melt and used to make photovoltaic cells. Two of the most promising of these ribbon materials are being developed with Flat-Plate Solar Array (FSA) project funding in contracts with Mobil-Tyco Corp. and Westinghouse Electric Corp. The Solar Energy Research Institute also sponsors the development of several promising ribbon concepts while still other proprietary ribbon approaches are privately funded. Additional technologies being developed to support low-cost silicon ribbon collectors are low-cost high-purity silicon feedstock, under development by several firms including Union Carbide Corp. which should achieve critical demonstration for quality and cost in early 1984, and the identification of low-cost, durable encapsulation packages for environmental protection.

In summary, while acknowledging the inherent uncertainty in any research activity, JPL and the Photovoltaics Program remain convinced that several, or more of the silicon technologies will exceed the 70¢/per peak watt target.

QUESTION RE-2

The Administration claims that the technology development and process development activities currently being funded at JPL should be and will be picked up by the private sector. What is your response?

ANSWER RE-2

JPL agrees with the fundamental premise of the Administration that the private sector should be responsible for technology development and short term, application-oriented R&D. The original plan for the Flat-Plate Solar Array project in 1975 was structured on the expectation that industry would do so in photovoltaics by the mid to late 1980's. The major questions relate to the timing of industrial assumption of this responsibility and the kinds of industry which is able to assume this responsibility as a function of the timing.

It is JPL's expectation that each of the technological developments it funds will, at some point, be picked up by industry. Our purpose is to stimulate the development of new photovoltaic technology that industry will find attractive. We do this primarily by funding and managing R&D contracts with private firms who both propose and conduct the actual research.

However, it is not presently true that, were JPL funding to be eliminated, industry would continue the development of photovoltaic collector and process technology at anywhere near the rate it is presently being pursued. Much of the work JPL pursues is quite fundamental in nature. All of it is either high risk or quite generic, applying to all photovoltaic technologies and firms. As a result, companies not able to appropriate the results of this work are not expected to continue it. In addition, much of the research JPL sponsors arises at small photovoltaic businesses that do not have much capital backing and whose sales are not strong enough to support significant R&D. Many of these firms presumably would not be able to find the means to continue their R&D without Federal support. (Of course, it is always possible that any particular research project might be continued without Federal support, but highly unlikely that most would.)

Many may feel that future silicon R&D belongs with industry since silicon modules are already successful commercial products. However, it must be recognized that silicon can be used as a photovoltaic conversion material in many different chemical and crystalline compositions. Sheets of single crystalline, polycrystalline and amorphous silicon can be formed or grown in a wide variety of ways. Silicon is often the basic conversion material, or part of it, in many of even the most advanced photovoltaic collector concepts such as stacked multijunction cells, photoelectrochemical cells, and luminescent dye concentrators. Thus, if it is argued that "silicon" R&D should be eliminated, one must be careful to select for elimination only those silicon photovoltaic conversion approaches that are, indeed, commercial or nearly so. In JPL's view, these are primarily the silicon ingot technologies. JPL and DOE have already phased out R&D related to silicon ingot as these processes have entered private development and commercial production. More advanced approaches have not yet reached a logical hand-off point.

Finally, much of the research JPL sponsors arises at small photovoltaic businesses that do not have substantial capital backing and whose sales are not strong enough to support significant R&D. Many of these firms would not be able to find the means to continue their R&D without Federal support.

QUESTION RE-3
What would you say are JPL's most striking achievements to date in the photovoltaics program?

ANSWER RE-3
JPL believes that the most striking achievement for which it can claim considerable credit has been the establishment of a dynamic, growing and technologically innovative domestic silicon photovoltaic collector industry. Of course, this effort has been a cooperative one between private U.S. industry and other Government laboratories in addition to JPL and all involved parties deserve credit. Major contributions of JPL's programs include:

- Developing and implementing an R&D management approach which created an effective working relationship among Government agencies, various laboratories and industry.
- Sponsoring advanced czochralski ingot technology development to a point where low-cost ingots can be grown and sliced to produce photovoltaic modules at less than $2.80/per peak watt* in an automated, balanced production line. Much of this technology is being incrementally adopted within existing industrial production lines.

- Achieving significant advances toward proof of the feasibility of producing low-cost silicon feedstock material to supply the photovoltaic industry. Future electronic grade silicon prices of \$15/Kg (1980\$) or less are expected compared to \$60-80/Kg today. Many of the advanced Seimen's technologies now being adopted in commercial silicon refinement plants were stimulated by JPL sponsored R&D.

- Demonstrating significant and important advances toward proof of the feasibility of low-cost silicon ribbon substrate technologies to enable modules to be priced for sale at \$.70/per peak watt or less. Several private manufacturers are now investing in further ribbon R&D and in commercial production equipment.

- Identifying of low-cost encapsulation packages to ensure durable, reliable photovoltaic modules. Several of JPL's in-house innovations (e.g.EVA) have been widely adopted by the industry.

- Developing collector designs, engineering, production processes and testing techniques and procedures that have worldwide recognition as "the best there is".

- The developing and assuring widespread industry adoption of photovoltaic collector costing models such as SAMIS, IPEG, and SIMRAND for use in determining the economic consequences associated with the many technical paths to low-cost silicon collectors.

- Developing and assuring widespread adoption by the photovoltaic industry of low cost cell and module processing technologies such as screen-printed metallization.

QUESTION RE-4

Do you see a need for JPL to carry out the same process and technology development activities for new thin-film photovoltaics materials, such as amorphous silicon, that it has for single crystal silicon?

ANSWER RE-4

Yes, we do. The manufacture of thin film photovoltaic cells and collectors differs from the manufacture of crystalline silicon photovoltaic structures in much the same way that the manufacture of integrated circuits differs from that of circuits assembled from discrete devices. The processing of individual photovoltaic cells is being replaced by building up collector assemblies, layer by layer, very possibly within the same production apparatus. The devices, the interconnect metallization, and much of the collector structure will be deposited by similar and compatible large-scale techniques, reducing fabrication costs by eliminating much of the handling required for manufacturing collectors with discrete cells.

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* All unspecified values are in 1980 dollars

These integrated thin film structures present a whole new spectrum of materials and chemical and electrical interfaces, along with a great many unknowns in reliability, durability, and potential failure modes. They also open up the potential for new areas in manufacturing technology which will require the development and modification of current laboratory techniques in order to satisfy scale-up requirements for volume production.

The differences between the technologies, in addition to providing a new set of problems to be addressed, strongly suggest the need and desirability of adopting the R&D approach which has worked so successfully in the past to this new set of related problems.

To date most of the effort in thin film technology has been to achieve an acceptable level of device performance in the laboratory, including investigations into the effects of structures and materials on the physics of the devices. Little attention has been directed towards identifying and choosing options in materials, deposition techniques, or device designs that would be conducive to scale-up. Likewise, there has been little attention paid to developing engineering designs for collectors, since it has been felt that such activities were premature. Those companies active in thin film photovoltaics within the United States have indicated that: 1) little has been done in thin film photovoltaic technology development, 2) it is badly needed, and 3) it is needed immediately. Recent discussions with Chronar, Ametek, and RCA personnel have disclosed very similar collector technology development, test and evaluation needs. The suggestion that Japanese experience in this area is directly relevant does not allow for either the restricted information flow because of the commercial status of the Japanese activity or for the fact that Japanese manufacturing activity in amorphous silicon modules has been directed mainly toward consumer markets with electrical outputs in the milliwatt range.

Initially, such activities would be primarily concerned with evaluating the performance of commercial thin film cells and modules (currently from Chronar and Japanese manufacturers). Similar testing would be made available to thin film manufacturers not yet offering a product for sale (i.e., RCA, Ametek, Photon Power, Arco Solar, etc.). This work would include assessments of stability, reliability, and durability for thin film cells and collectors. As the activity progresses investigations of materials interfaces, environmental isolation, and process step compatibility would be pursued.

QUESTION RE-5

How have the photovoltaic firms you deal with responded to budget cuts in the DOE in photovoltaics program? Have they increased their efforts to compensate?

ANSWER RE-5

It has been JPL's experience that the funding cutbacks in JPL sponsored silicon R&D have led to:

(1) a significant decrease of corporate silicon R&D funding at most (but not all) contractors

(2) a reduction in risk taken by the silicon photovoltaic industry

(3) an increased inhibition to the flow of R&D information as complete, privately funded development increase..

JPL believes that the upper-level managements of some firms have interpreted the recent cutbacks in Federal funding of silicon R&D as indicating a lack of promise for the technology. In addition, many of the smaller independent firms which conduct R&D under JPL sponsorship simply do not have the capability to support this research internally.

One of the few significant cases of contractors continuing work with their own funding has been in silicon refinement. Union Carbide has increased its funding of silane technology and Hemlock has increased its funding of its dichlorosilane technology. It is important to note that both of these feedstocks and their silicon deposition process steps have important commercial possibilities outside the photovoltaic market. However, neither company has compensated for the DOE Program cutbacks in the deposition technology which is critical to low-cost silicon collectors.

Funding cuts for silicon ribbon growth have led to mixed observable results. Reduced Federal funding for Westinghouse has led to a reduced level of support from within the company. Mobil Tyco has been so often disappointed due to funding cuts that they are continuously reviewing the value of maintaining any contract with JPL. More and more of their work is funded and conducted on a proprietary basis to which the PV R&D community has no access.

Spire is typical of many of the smaller, independent firms JPL has contracted with for R&D. Spire has been directly and severely affected by DOE funding cuts in photovoltaic environmental isolation. In 1980 Spire received a $320K contract from JPL to continue development of electrostatic bonding techniques. In March of 1981 the effort was terminated because of DOE funding cuts. Spire is a small company devoted to the solar industry. It is not possible for them to compensate with in-house funding. For the same reason no other contractors working on environmental isolation have been able to continue work with their own funding. Thus, the total rate of progress in this area has slowed dramatically.

Module manufacturers have been affected by cutbacks in the block-buys of state-of-the-art solar array modules. RCA dropped out of the Block V program because of a lack of DOE funds to complete development of a lamination machine which was essential to the fabrication of their Block V modules. ARCO Solar decided not to continue work on their Block V batten-seam residential module without DOE funding.

The above are just a few specific examples out of many which indicate that industry is not yet ready or in many cases, able to offset the steady decreases in DOE Program R&D funding which have occurred over the past two years.

QUESTION RE-6

Are photovoltaic cells still following the cost reduction curves set out for them by DOE in 1979? Have the cutbacks in the Federal photovoltaic budget kept costs from coming down as rapidly as DOE envisaged in earlier years?

ANSWER RE-6

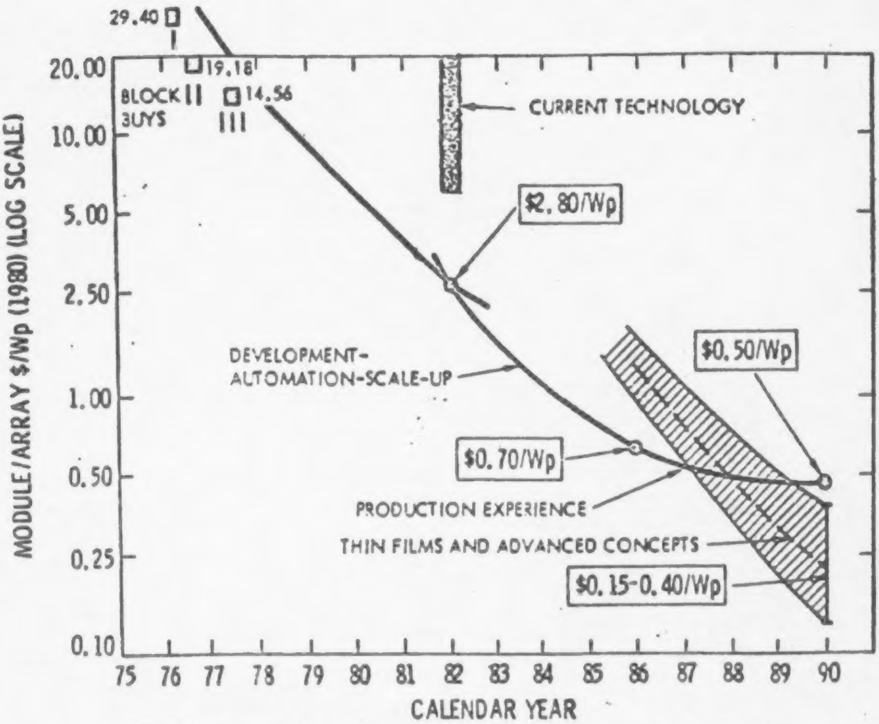
The cost reduction curves referred to in the question are presumed to be those which have represented module prices as a function of calendar year . This can be seen in Figure 1. These prices through the formal block buys of the project reasonably track the curve until calendar year 1980. The initial decreases in price are traceable to larger stable orders and the inclusion of some new technology in the processing activity. The module prices are not expected to continue to track those curves because we do not anticipate that industry will adopt new technologies as rapidly as they might have had the program continued as planned.

The original and most widely known price goal was that established for photovoltaic modules at 70¢/per peak watt, 1980 dollars, targetted for technical readiness in 1982 and commercial availability in 1986 at the technical readiness milestone the process required to permit a manufacturer to produce and sell at the indicated target price were completely identified, although not yet commercially purchased and installed in a factory of sufficient size to permit meeting the goal. Commercial availability in 1986 provided them four years for decision-making, capital acquisition and implementation of factories which could produce and sell profitably at the 70¢/per watt goal. Meeting the 1986 schedule required, that at least one plant having a capacity of 30-50 megawatts a year be in existence, Table 1.

After the initial goal had been established intermediate goals were identified, the most significant of which was the $2.80/per peak watt (1980 dollars) technical readiness goal which was targetted for 1980. The formal review board including members from the venture capital industry established in the fall of 1980, agreed that the technical readiness target had been met. Note that collectors priced at $2.80/per peak watt were predicted to become available in 1982. This has not happened even though the $2.80/per peak watt technical milestone was achieved on schedule. Present collector prices range from $6 - $20 per peak watt depending on order size, manufacture and collector type. Recent press announcements and private communications between DOE and manufacturers indicate that lower prices may be imminent. Present worldwide photovoltaic sales of 11.6 megawatts are not large enough to support the scale of production technology which is necessary to achieve the $2.80 price. Studies have indicated that 30 megawatts peak produced in a single factory would also be required to achieve this goal.

The technologies required to achieve the 70¢ peak watt goal in 1986 and targetted for technology readiness in 1982 are the advanced technologies whose ability to meet the schedule is severely compromised by the cut-backs in the Federal photovoltaic budget. Note that the $.70/Wp goal has already slipped two years and may slip further or be dropped entirely.

Figure 1.



SOURCE: Photovoltaics as a Terrestrial Energy Source, Vol. II, Feb. 1980, DOE, p. 4-13

Figure 1. DOE Photovoltaic Program Collector Cost Goals
(1980 $)

Table 1. BUDGET IMPACT SUMMARY

| ANNUAL PROGRAM BUDGET ($ million) (level for five years) | $90 | $74 | $55.6 | $37 | $27 |
|---|---|---|---|---|---|
| LTF $.40/Wp Collector | 1986 | 1987 | 1987 | 1987 | 1987 |
| | | | .50* | .34* | .25* |
| TF $.70/Wp Collector | 1984 | 1985 | 1986 | ** | ** |
| TF $.50/Wp Collector | 1988 | 1989 | 1990 | ** | ** |
| TF $.40/Wp Collector | 1989 | 1990 | ** | ** | ** |

* Probability of success.

** Milestone dropped from federal program at this budget level. May be picked up by industry.

LTF- Laboratory Technical Feasibility

TF- Technical Feasibility

QUESTION RE-7

What further steps are needed to complete technology development on the parabolic dish solar technology? How many more years will DOE have to fund this program before it can be turned over to private industry?

ANSWER RE-7

In order to properly address the questions posed, two definitions are needed. The first defines the completion of technology development; the second, the point at which the program can be turned over to private industry. It is our view that technical feasibility for components and subsystems is demonstrated when an adequate period of testing has been successfully completed in which basic technical objectives are met. In general, this testing must be done at the system level in order to demonstrate the successful interaction of the components and subsystems.

The point at which the private sector will continue to move the technology toward commercial readiness without further Federal support is less clear. However, we believe that for the dish program this means the completion of second generation subsystems development, at a minimum. At that time, efficiencies and the maturity of the designs should be such that there will be a reasonable probability that these technologies, when produced in quantity, will compete with conventional generation methods.

It is also our position that technology development must be supported by a continuing research and advanced development activity to address technical barriers that must be overcome and to establish a technology base that will act as a springboard for future development and improvements.

Finally, we believe that successful technology development requires the demonstration of this technology at the system level and in the case of the dish solar thermal systems this means at a multi-module size sufficiently large to understand the interaction of the technology with the utility or potential user. Such a test when viewed as an experiment need not be large but will be of a size appropriate to the application in question; generally, a few modules will suffice. The results of these experiments will be to provide feedback to the industrial developers and information for the user industries.

The dish program, starting later than other solar thermal technologies, is nearing completion of first generation systems. By the end of 1983 both organic Rankine and Stirling modules will have been tested and system-level experiments underway. (The Small Community Experiment will provide the vehicle for the Organic Rankine Cycle (ORC) system test and, depending on FY 1983 funding, the Stirling, as well.) The first generation Brayton module system, paced by the automotive engine development program, will be complete by the end of 1984.

The second generation module development is projected to start in FY 1983. The major task in this regard is an advanced concentrator that utilizes experience gained in both the first generation dish development and the heliostat programs. This concentrator would be suitable for both advanced Stirling and Brayton engines. In addition, we will continue to integrate the automotive Brayton engine developments into the dish program as progress toward higher temperatures and ceramic components is made. Similarly, work will be done to advance Stirling engine technology by developing ceramic heater head components. Completion of a second generation module is planned for FY 1986.

In summary, the steps needed to complete first and second generation dish technology development are:

| | | |
|---|---|---|
| 1. | Complete Organic Rankine Cycle module development | 1983 |
| 2. | Conduct Organic Rankine Cycle Small Community field experiment | 1983-1985 |
| 3. | Complete 1st generation Brayton module development | 1984 |
| 4. | Complete 1st generation Stirling module development | 1984 |
| 5. | Conduct Brayton and Stirling field experiment | 1984-1986 |
| 6. | Initiate and complete 2nd generation concentrator development | 1983-1986 |
| 7. | Complete 2nd generation module development (Brayton and/or Stirling) | 1986 |
| 8. | Conduct 2nd generation field experiment | 1986-1988 |

On this basis and the assumption that second generation technology will be competitive with conventional generation techniques, it is reasonable to assume that the technology development part of the DOE dish program could be terminated in 1988. Beyond this time, there would be a sufficient economic incentive to permit industry to proceed with commercial development on its own.

In summary, in our view, a program that will take the development of the dish technology to the point that industry will assume responsibility for commercialization is a six-year program consisting of the following major elements:

- Research and advanced development to further the establishment of a sufficient technology base

- Completion of first and second generation technology development

- Field experiments to test the dish hardware at a system level

For the dish program as a whole, a funding level averaging approximately $12 million per year over the next six years would be adequate. Specific recommendations for this program are as follows:

| Program Element | FY<br>1983 | 1984 | 1985 | 1986 | 1987 | 1988 |
|---|---|---|---|---|---|---|
| Research & Advanced Development | 2 | 2 | 2 | 2 | 2 | 2 |
| Technology Development | 10 | 8 | 9 | 6 | 2 | 1 |
| Field Experiments | 5 | 3 | 1 | 6 | 3 | 2 |
| Total | 17 | 13 | 12 | 14 | 7 | 5 |

QUESTION RE-8

Why is it an appropriate step for the Federal Government to fund a large solar pond demonstration at Salton Sea? How does that demonstration fit in with the rest of the solar pond program?

ANSWER RE-8

It is not appropriate for the Federal Government to fund a large solar pond demonstration at Salton Sea. However, it is appropriate for the Federal Government to participate in and, if necessary, fund a significant solar pond field experiment directed at large ponds generating electricity. The Salton Sea is an attractive site but not the only site for such an experiment.

In the written testimony the characteristics of an effective field experiment were identified. Such an experiment is very much needed in the salt pond R&D activity. The effective and detailed definition of such an experiment is an important activity to undertake, because the process of detailed definition will more clearly identify those areas where R&D support is needed to remove uncertainties.. The Salton Sea site has the distinct advantages of:

- High solar insolation
- Variable wind conditions during the year to expose the field experiment to significant wind disturbances.
- Representative of many locations where brine enhancement is required for successful pond operation.
- Convenient for both dike and dug pond construction.
- Providing a benefit to the State of California in a number of desalination projects.
- Strong local support because of the environmental benefit of controlling lake salinity.
- Support from Southern California Edison, a local utility interested in following the experiment with a privately funded demonstration.

A field experiment of significant size for generating electricity is a necessary component of a U.S. R&D program. No such experiments have been built in the U.S. Detailed planning of an electricity-producing salt pond at this time provides useful feedback to the R&D planning process and takes maximum advantage of the R&D activities presently underway. A schedule for a large electricity producing salt pond is such that R&D for the next several fiscal years would also be applicable and be able to be used in such an activity.

QUESTION RE-9

In August 1980, SERI did a comparative study of different solar thermal electric systems in the 1-10 megawatt electric range. They found shallow solar ponds to be the least economic by far - producing electricity at about 40¢/KWH. What leads JPL to believe that solar ponds are a viable option for generating electricity?

ANSWER RE-9

The reference report "Final Report: A Comparative Ranking of 0.1 - 10 MWe Solar Thermal Electric Power Systems" did not cover salt-gradient solar ponds of the type successfully operated in Israel and the U.S. The concept studied (and which should be identified with the 40¢/KWH cost of electricity) used a field of shallow, saltless "ponds" (plastic, inflated bags) with external storage in thermoclines. Data from ORMAT (Israel) on their model tests and projected 5 - 50 MWe salt-gradient pond designs appeared highly competitive.

Since 1979, additional test data from ORMAT and design studies of 1 - 50 MWe salt gradient ponds by SERI, Utah State, Arizona State, DOE, JPL, University of Dhahran, Southern California Edison, Flow Industries, EPRI, Pacific Northwest Laboratory and others have all shown that given the right set of circumstances (usually, low cost land, availability of salt and water plus reasonable insolation) salt-gradient ponds are highly competitive - producing electricity at 3¢ - 10¢/KWH. Southern California Edison internal studies of the Salton Sea application have shown costs of electricity in the range of 4-5¢/KWH for the 5 - 50MWe modules. The regional applicability and potential of salt-gradient ponds in the U.S. is covered in JPL Report 5107 dated March 8, 1982. This report shows a potential of some 8-9 quads of energy and that ponds are generally applicable throughout the U.S.

These comments have been discussed with Dr. Barry Butler of SERI and he has offered to update you on SERI's position on salt-gradient ponds if you so request.

QUESTION RE-10

What level of effort is required over the next few years to maintain an adequate technology development program for photovoltaics? For parabolic dishes? For the photovoltaics program as a whole?

ANSWER RE-10

In answering this question, we believe that it is necessary to define the term "adequate" within the President's policy of funding long range, high risk research and development while leaving market development, industrialization and commercialization activities to be addressed and funded by industry.

In our view, an adequate program would sponsor research and development targeted at making feasible the production by industry of photovoltaic systems that can be sold at prices ten times less than current prices. This program would focus on advanced concepts, components and systems that when proven feasible will be picked up by industry for completion of development and commercialization. The program must not only prove the technical feasibility of photovoltaic devices, but must address each of the critical technical barriers to be overcome before industry can complete development and manufacture of photovoltaic components that can be fielded in systems and provide electrical energy at prices competitive with conventional generation methods.

The technical barriers that must be overcome include development of efficient, low-cost cells, and development of long-life materials for interconnecting those cells and encapsulating them for protection from the environment. Not only must materials be developed but we must address several key, high-cost manufacturing steps that offer potential for high payoff. Furthermore, development of flat plate and concentrator collectors alone may not be sufficient for acceptance of photovoltaic technology. There are important technical problems associated with converting the energy collected at varying power levels over the day in the form of DC electricity to AC electricity of a quality acceptable to a utility. These issues are high risk, high payoff, and the technology is not yet to the point where industry can be expected to complete this development on their own. Finally, we must perform experiments with systems to learn how the components interact within the photovoltaic system and with the utility grid. These experiments provide feedback for collector and component research and development projects and are necessary to prove feasibility and transfer technology to the photovoltaic industry and to the utilities. These activities are not only appropriate, but necessary to arrive at that point of technological maturity where it becomes economically feasible for industry to complete development with private funding.

For the Photovoltaics program as a whole, funding at a level of approximately $84 million per year over the next five years would be adequate. Of this total we recommend an average amount of $48 million per year for the Technology Development portion of the program. Our specific recommendations for this five-year period are as follows:

| | FY | | | | |
|---|---|---|---|---|---|
| | 83 | 84 | 85 | 86 | 87 |
| ADVANCED R&D | 37 | 37 | 37 | 37 | 32 |
| TECHNOLOGY DEVELOPMENT | | | | | |
| Component Technology Development | 33 | 38 | 40 | 38 | 33 |
| Systems Engineering & Standards | 5 | 4 | 4 | 3 | 2 |
| Tests and Applications | 11 | 10 | 10 | 6 | 4 |
| TOTALS | 86 | 89 | 91 | 84 | 71 |

The definition of an adequate parabolic dish program is contained within the response to question RE-7. In summary, a program that will take development of dish technology to the point that industry will assume responsibility for commercialization is a six-year program consisting of the following major elements:

- Research and advanced development to further the establishment of a sufficient technology base
- Completion of first and second generation technology development
- Field experiments to test the dish hardware at a system level

To complete the dish program a funding level averaging approximately $12 million per year over the next six years would be adequate. Specific recommendations for this program are as follows:

| | | | | FY | | |
|---|---|---|---|---|---|---|
| Program Element | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 |
| Research & Advanced Development | 2 | 2 | 2 | 2 | 2 | 2 |
| Technology Development | 10 | 8 | 9 | 6 | 2 | 1 |
| Field Experiments | 5 | 3 | 1 | 6 | 3 | 2 |
| Total | 17 | 13 | 12 | 14 | 7 | 5 |

## QUESTION RE-11

Do you believe the current (FY 1982) photovoltaics program is properly balanced between advanced research, technology development and systems R&D?

## ANSWER RE-11

JPL does not believe that the current (FY 1982) appropriation for the photovoltaics program is properly balanced between advanced research, technology development and system R&D. The FY 1982 budget is seriously unbalanced, with almost 79% of the total program budget allocated to Advanced Research and Development.

QUESTION RE-12

Have you done any studies of the effects of different Federal photovoltaics budget levels on industry's ability to meet the cost goals in the Photovoltaics RD&D Act? Could you please summarize the results of those studies and provide copies for the record?

ANSWER RE-12

The Act's cost goal for complete photovoltaic systems ($1.40/per peak watt 1980$) appears to be attainable only with the most advanced, inexpensive and efficient photovoltaic collectors imaginable (i.e., 15¢/per peak watt). However, DOE's cost goals as originally established for collectors can be met and exceeded (See Question RE-6 above) and DOE's system cost goals, shown in Table 2, also can be met.

Many studies have been completed which examine the likelihood of achieving the various cost goals of the program. One of the most important of these was submitted to Congress by DOE in 1980 and is entitled Federal Policies to Promote the Widespread Utilization of Photovoltaic Systems. Table 3, taken from this study, shows when the Act price goals (as modified by DOE) would be met under seven different options for Program funding and strategy, where the options differed primarily in the amount of money spent on commercialization and market development.

More recently, an internal study was completed which examined the likely effect of different budget levels on the ability of the Federal photovoltaic Program to meet the collector cost goals (See Question RE-6, Table 1). This study showed that the Program's ability to reach collector technical feasibility goals is strongly dependent on federal R&D budget levels. And, as discussed above in Question RE-2, JPL believes and the evidence suggests that the pace of private industry's photovoltaic investments is likely to slow significantly should the R&D momentum sustained by the photovoltaic Program be lost.

Table 2. Commercial Readiness Goals

| Application | Installed System Price (1980$) per peak watt | Calendar Year Of Achievement |
|---|---|---|
| Remote, International | $6.00-$13.00 | 1982 |
| Residential | $1.60-$2.20 | 1986 |
| Intermediate Load Center | $1.60-$2.60 | 1986 |
| Central Station | $1.10-$1.80 | 1990 |

Source: PV Multi-Year Program Plan, draft, DOE, Sept. 1980

## Table 3

DOE Program Costs and Impacts for Seven
Alternative Photovoltaic Programs[1]

| PROGRAMMATIC OPTIONS | DOE PROGRAM COST (billion $ current) | | | | YEAR OF EVENT | | CUMULATIVE INSTALLED GWp BY END OF YEAR | | |
|---|---|---|---|---|---|---|---|---|---|
| | TOTAL | AR&D | TD&A | MD | THE ACT[2] PRICE GOALS FIRST MET | 1 QUAD/YR FUEL DISPLACEMENT | 1988 | 2000 | 2010 |
| THE ACT BUDGET: | | | | | | | | | |
| OPTION 1 | 1.4 | 0.45 | 0.47 | 0.48 | 1993 | 2005 | 0.04 | NA[3] | NA |
| OPTION 2 | 1.5 | 0.25 | 0.51 | 0.72 | 1991 | 2003 | 0.13 | 29 | 161 |
| OPTION 3 | 1.6 | 0.45 | 0.71 | 0.43 | 1991 | 2006 | 0.08 | 16 | 95 |
| ENHANCED MARKET DEVELOPMENT: | | | | | | | | | |
| OPTION 4 | 2.4 | 0.45 | 0.71 | 1.26 | 1988 | 2000 | 0.5 | 59 | 202 |
| OPTION 5 | 3.0 | 0.45 | 0.71 | 1.85 | 1986 | 1998 | 1.0 | 77 | 222 |
| OPTION 6 | 3.8 | 0.45 | 0.71 | 2.62 | 1986 | 1998 | 1.6 | 90 | 237 |
| THE ACT QUANTITY GOALS: | | | | | | | | | |
| OPTION 7 | 5.0 | 0.45 | 0.71 | 3.84 | 1986 | 1997 | 4.0 | 93 | 239 |

[1] Calculations shown in this table were made using a market diffusion model discussed in Section 7.4 of Volume II. Relative impacts are predicted more accurately than absolute values of impact. See Table F-5 for impacts from successful advanced collector development.

[2] As modified by DOE (see Section ES.2.3). DOE program funding ends in 1988 for all options. Solar tax credits are required to attain price goals for Options 1, 2, 3, (see Table F-4).

[3] Impacts from silicon systems not predicted.

Source: Federal Policies to Promote the Widespread Utilization of Photovoltaic Systems, Feb. 1980, DOE.

## ROGER G. LITTLE - SPIRE CORPORATION - BEDFORD, MASSACHUSETTS

Responses to Questions From Mr. Fuqua to Mr. Little
August 11, 1982.

1. QUESTION: What level of effort do you think is required to maintain an adequate federal photovoltaics program over the next few years?

RESPONSE: Based upon the federal investment in photovoltaics, the associated progress made to date and the requirements for future R&D activities to achieve photovoltaic goals, a budget of approximately $100 million per year over the next few years is required. An estimate of the total amount of federal investment to achieve utility-ready photovoltaics is $500 million.

2. QUESTION: Do you believe the current federal program (FY'82) is properly balanced between advanced research, technology development and systems R&D?

RESPONSE: Except for the resources being expended in the SMUD and Georgetown demonstration projects, I believe the federal program for FY'82 is properly balanced, although below required funding levels. The resources assigned to the demonstration projects would better be spent by distribution over advanced research and technology development programs.

3. QUESTION: Do you think a JPL Flat Plate Solar Array project has been a help to industry? What would you say have been its principal achievements?

RESPONSE: The JPL technology development project has been the most important contribution to the photovoltaic industry made by the federal government to date. The JPL program initiated much of the technology, small companies, and general directions which have since been absorbed by major energy companies who are now pursuing PV commercialization. In addition, JPL has set high industry standards by its activities.

4. QUESTION: Do you think JPL should play the same role in the future for thin film materials that it played in the past for flat plate silicon?

RESPONSE: JPL should play the same role in the future for thin film materials that it has played for single crystal CZ materials in the past. As advanced concepts whose potential for achieving low-cost, high-efficiency photovoltaics are identified at SERI, these materials should flow to JPL for technology development involving strict costing analysis, low-cost process development, durability assessment, and large scale manufacturing approach determination.

5. QUESTION: How serious do you believe foreign competition is likely to become in the next few years for the U.S. photovoltaics industry?

RESPONSE: Foreign competition is becoming more serious each day. Both the Europeans and the Japanese have extensive PV programs underway. Also, in many cases they have stronger marketing ties to third world countries where the major near-term markets for photovoltaics exist.

6. QUESTION: Do you believe the 15% business investment tax credit for renewable energy should be extended to 1990 as proposed in H.R. 6735?

RESPONSE: As this tax credit relates specifically to photovoltaics, it will be needed to the year 1990.

### INSTITUTE OF ENERGY CONVERSION - UNIVERSITY OF DELAWARE

### RESPONSE TO HOUSE COMMITTEE QUESTIONS
T.W.F. RUSSELL

1. The photovoltaics program had a budget of about $151 million in 1980. We recognize the need to cut government expenditures but we feel that stable multi-year funding of at least $100 million per year is essential to maintain critical size research programs and groups, and to encourage effective university and industrial interaction.

2 The federal program should be principally focused on advanced research in electronic materials, device design and analysis, and fundamental engineering research which prepares the way for evaluation of commercial-scale production. Technology development should be carried out by industry in a cooperative effort involving government and university laboratories. Large-scale systems R&D should be conducted in cooperation with utilities, probably through EPRI. Smaller scale systems research will be conducted by industry as their proprietary needs require it. With respect to FY 82 as defined on the attached sheet, I would like to comment as follows:

In its official budget request to Congress, DOE requested a FY 82 photovoltaic budget of $62.9 million with $44 million allocated for advanced research and development (AR&D). The pertinent page is presented as Attachment 1. As indicated in the Key Activity Summary of the Budget Request, the focus of advanced research and development is to "continue the development of advanced thin films" -- a task which does indeed fit the Administration's criteria of being advanced, high-risk research. However, scrutiny of the berakdown of AR&D budget request reveals that only about $18 million is allocated for AR&D, the first five items on the list. The remaining $26 million appears to be allocated for technology development pertaining to the more mature silicon technology; e.g., $5 million for "Improved Single Crystal Silicon Device Development". The major contracts for all these programs have been awarded to "Government-Owned Contractor-Operated" laboratories such as the Jet Propulsion Laboratory (JPL) and the Solar Energy Research Institute (SERI).

In short, while ostensibly complying with Congress and the new Administration's policy, DOE and its principal contractors appear to be maintaining a bias toward technology development and demonstration projects. This bias is reflected in the fact that the Solar Energy Research Institute (SERI) which manages the AR&D Subprogram, has been notified that it will receive a budget of $18.2 million. The balance of the $44 million AR&D request appears to be destined for the technology development, assessment and demonstration where it will support JPL and industrial organizations.

3. SERI is pursuing a minimal program in thin-film solar cells, totally constrained by the present funding levels with only significant efforts in $CuInSe_2$, $Zn_3P_2$, CdTe and amorphous silicon. There is virtually no scope for exploring or developing new materials which have not proven photovoltaic potential; neither can some general research needs be explored such as basic studies of the interrelation between thin-film deposition procedures and electronic/optical properties. Budgeting constraints have already eliminated $Cu_2S$-based solar cells from federal support, even though it is one of the most attractive material systems from both cost and resource availability viewpoints.

4. We make a serious mistake when we look for a single "winner" in thin-film solar cells. Much of the fundamental scientific and engineering knowledge gained from the research will be of general applicability and it is unimportant which specific system was used for its development. It is highly likely that a number of material systems will have significant commercial success satisfying differing operational and economic needs. Two general classes of materials are certain to be important, amorphous and thin-film polycrystals. It is also most premature, for instance, to eliminate from our research effort solar cells made from organic semiconductors.

5. Foreign competition will be a major consideration both for international and U.S. markets. Cooperative research efforts among industry, government and universities in countries such as Japan are producing commercial results that are superior to what we have been able to achieve in the USA. It is even more discouraging to realize that this has been achieved using fundamental research results from U.S. laboratories.

6. The tax investment credit should be maintained and serious consideration given to other measures to more equitably position solar conversion with respect to fossil fuels. The value to the nation of uninterruptible non-polluting domestic energy supplies must be reflected in the entire federal subsidy-taxation picture.

## ATTACHMENT 1

Photovoltaics..........$160,200,000..........$160,200,000..........$62,900,000

The objective of the Photovoltaic Program is to maintain high probability of major photovoltaics research breakthrough, which will result in array prices of $.15 - .40 per peak watt (1980$), with systems cost of $1.10 - 1.80 per peak watt by undertaking advanced R&D. This will permit penetration of centralized utility markets. The program continues to leverage industry, which thus far has spent about $50,000,000 on R&D, constructed about $50,000,000 of manufacturing capacity, and has shown willingness to cost share at the 40% level in residential experiments.

Effort will be conducted in two areas: Advanced Research and Development and Technology Development. The FY 1932 funding for these elements are as follows:

a. Advanced R&D..............................................$44,000,000

The Advanced Research and Development effort will fund:

- Polycrystalline silicon devices ($5,000,000)
- Amorphous Silicon material devices ($5,000,000)
- Other thin-film devices ($4,000,000)
- Basic photovoltaic research measurements, insolation studies ($2,000,000)
- SERI Photovoltaics research --In-house ($2,000,000)
- Advanced innovative concentrator devices and subsystems ($4,000,000)
- Advanced systems research ($6,000,000)
- Improved single crystalline silicon device development ($5,000,000)
- Advanced systems components development ($3,000,000)
- Supporting research and development ($4,000,000)
- Silicon material development ($4,000,000)

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QUESTIONS AND RESPONSES

Dr. J.F. Schaefer

to the

Subcommitte on Energy Development and Applications

QUESTION: What level of effort do you think is required to maintain an adequate federal photovoltaics program over the next few years?

ANSWER: For reasons of consistency and honesty I must stick with my testimony of July 28, 1982. In it I said that $27 million per year was clearly too little, and implied that I was very comfortable with about $150 million per year. To be absolutely truthful, I am not positive that $150 can be wisely spent now, given that staffing at DOE, JPL, and Sandia has been reduced. Based primarily on my observation of current activity, I believe that the right number is more than $80 million but not more than $100 million . . . unless the administration agrees that indeed we should have a war on energy dependence.

QUESTION: Do you believe the current federal program (FY '82) is properly balanced between advanced research, technology development and systems R&D?

ANSWER: Nearly so. Paradoxically, the heavy investment by private industry in advanced PV materials and cell research means that perhaps the Federal allocation to that area can be reduced. I would reapply the funds to technology development and systems R&D For example, for relatively small amounts of incremental funding the staffs of the Residential Experiment Stations could perform vital experiments allowing us to fully quantify the effects of various roof mounting schemes upon PV array operating temperatures. Such phenomena are not being investigated by our industry now, but must be understood because of their impact on both system performance and longevity.

QUESTION: From your experience with the Southwest Residential Experiment, what are the most important systems problems remaining to be solved for photovoltaics?

ANSWER: There are no remaining major problems, but many important minor issues persist, all of which are related to performance, lifetime, on life-cycle cost. Photovoltaic cell operating temperature, mentioned above, is one such issue. Inverter performance/cost trade off is another. There are a host of still-unresolved technical issues associated with the utility interface, such as inverter run-on upon loss of utility as discussed in my original testimony. Probably most important, new-technology, presumably lower-cost PV modules must be fielded as soon as available so as to obtain performance and durability data early-on. I strongly believe that every single unknown and/or doubt, however minor, should be resolved as soon as reasonably possible in order to essentially guarantee public/utility/building industry acceptance and early inplementation of PV systems of all sizes.

QUESTION: What is your impression of the Sandia systems R&D program? Is it well run? Are they addressing the right problems? Have they been easy to work with? Do you get the kind of technical assistance you need?

ANSWER: My responce to most facets of this multiple question is positive, although I am unsure of the precise scope of the question (I am not sure what is meant by "system R&D" program. I interpret it as all SNLA PV work). Yes, I believe it is well run by a too-small staff. For example, I am positive that SNLA should have more personnel devoted to monitoring SW RES and NE RES effort and results (SNLA appears to be rectifying this deficiency). I strongly believe this understaffing to be a direct consequence of uncertainty of funding and, therefore, uncertainty of personnel regarding their professional futures. I also have difficulty in attracting and retaining experienced professionals given the uncertainties of the future. Those uncertainties must be removed if we are to achieve the most possible results for the funds invested.

Regarding the question "Are they addressing the right problems?", the answer is yes, but there are others that also should be addressed, and soon, but are not due to funding limitations. I would not have split the present funds differently than SNLA did, but . . . as said above . . . more could be effectively used. The SNLA staff are both perceptive and flexible; if higher priority areas surface I have little doubt that the effort will be redirected.

Regarding the question "Have they been easy to work with?", an unqualified "yes!"

Regarding the question "Do you get the kind of technical assistance you need?", No, not totally. Reason, again, is understaffing.

QUESTION: How serious do you believe foreign competition is likely to become in the next few years for U.S. photovoltaics industry?

ANSWER: Very serious. I have no basis for elaboration beyond that given in my original testimony.

QUESTION: Do you believe that 15 percent business investment tax credit for revewable energy should be extended to 1990 as proposed in H.R. 6735?

ANSWER: I do not know the genesis of the 1990 date as opposed to, say, 1987. I have not read H.R. 6735. I support an extension, but am optimistic enough to believe that an extension to 1990 will not be necessary. Most renewable options do not require eight year lead times. I cannot personally argue strongly for the 1990 date.

## DANIEL J. SHINE, JR. - SANDERS ASSOCIATES, INC. - NASHUA, N.H.

### Questions to Mr. Shine

What do you believe is the level of effort required over the next few years to maintain an adequate solar thermal R&D program?

What do you believe the Federal Government should do in the next few years for solar thermal technologies not covered by your testimony, i.e. solar ponds and hemispherical bowls? Do you support the Salton Sea or Crosbyton demonstration projects?

Do you believe the business tax credits for renewable energy systems should be extended to 1990 as proposed in H.R. 6735? Should they be made available to utilities?

You recommend on page 9 of your testimony support for the parabolic dish technology development program at $15-$20 million per year through 1986. What activities would such a level of effort support?

On page 6 of your testimony you describe the advantages of the Brayton cycle engine for parabolic dish technology. What are the disadvantages? What problems need to be resolved?

Dr. Brown states in his testimony that parabolic dish systems are not likely to be as attractive to utilities as central receivers because of lack of storage and "the potential for high maintenance costs of a large number of a large number of small components." Could you comment on those observations?

QUESTION: What do you believe is the level of effort required over the next few years to maintain an adequate solar thermal R&D program?

RESPONSE: For the balance of the 1980's, the Federal Government should support research on and development of solar thermal systems that:

A. Show promise for effecting both near and long-term improvement in the cost of energy and/or efficiency in the production of electricity and process heat.

B. Produce chemicals, with a special emphasis on reduction of energy costs associated with existing production processes.

C. Produce liquid and gaseous fuels from renewable and non-renewable feedstocks.

D. Lead to cost effective methods for the disposal of waste products, particularly hazardous waste.

In the near term, specifically FY83 to FY86, Federally sponsored solar thermal R&D should emphasize technologies and processes associated with Category A (above). Programs in the following areas should be supported:

1. Component and Subsystem Cost Reduction/Efficiency Improvement.
2. Energy Storage.
3. Exploratory experiments which offer potential of high longterm payoffs in terms of reduced energy costs, conservation of fossil energy resources, reduced foreign imports, and environmental quality improvements.

A results oriented solar thermal program which could address each of these areas could be conducted for about $50 million to $60 million a year over the FY83-86 time frame. Funding at this level would 1) facilitate completion of projects currently underway involving central receiver, parabolic trough and parabolic dish technologies; 2) provide for initiation of several longer term research and development projects, and 3) support the research facilities at Georgia Tech, Sandia Albuquerque, and Edwards Air Force Base which are so critical to the development of these technologies. On this point, I will paraphrase the conclusions of a solar thermal industrial group at a May 1982 workshop:

There was a strong recommendation that the undertaking of the longer-term R&D work by the Federal Government should be done in consonance with the completion by the Federal Government, of several on-going technology programs that are close to being turned over to the private sector. In particular, the central receiver, parabolic trough, and parabolic dish programs, must be completed as the longer-term R&D work outlined above gets underway. In fact, the goal of Federally sponsored R&D work must be to achieve a state of readiness in which a given technology can be taken over by the private sector, and thereby, be made available as a viable energy option at the earliest possible time. Thus, the recommendations made for long-term R&D for the 1980's must not be construed as a recommendation that the Federal Government abruptly delete support for the three technologies which are in the process of being taken over by the private sector. These three technologies, and hopefully, others that will follow from long-term R&D projects, must be phased out in a logical, timely manner in accordance with the ability of industry to accept and complete final development and to commercialize.

QUESTION: What do you believe the Federal Government should do in the next few years for solar thermal technologies not covered by your testimony, i.e., solar ponds and hemispherical bowls? Do you support the Salton Sea or Crosbyton demonstration projects?

RESPONSE: I am not qualified to respond to this question. Sanders engineering staff has not conducted any research whatsoever in solar ponds and has only scanned the technical reports associated with the hemispherical bowls. As technologists we support both the Salton Sea and Crosbyton projects but are not in a position to evaluate the merits of either project vis-a-vis other solar thermal technology projects.

QUESTION: Do you believe the business tax credits for renewable energy systems should be extended to 1990 as proposed in H.R. 6735? Should they be made available to utilities?

RESPONSE: Sanders endorses extension of the business tax credits for renewable energy systems to 1990 as proposed in H.R. 6735. These credits should be made available to utilities, as the utilities represent the largest single market segment potentially available to solar thermal equipment manufacturers. For example, with the Federal and State credits now available, Southern California Edison will sign a letter of intent for up to 50 MW worth of solar thermal electric modules or systems if the potential supplier can demonstrate and guarantee system performance and meet specific delivery and installation requirements. This circumstance points out the present dilemma facing solar thermal equipment developers: without "demonstration" hardware in place to prove the viability of the equipment no sales can reasonably be discussed, thus the need for continued Federal support for the more advanced technology systems "demonstrations". Further, even with such Federal support, without the existing tax credits the initial sales absolutely necessary to establish the industrial base will never take place.

QUESTION: You recommend on Page 9 of your testimony support for the parabolic dish technology development program at $15-20 million per year through 1986. What activities would such a level of effort support?

RESPONSE: Federal support of the parabolic dish solar thermal development program at $15-20 million per year through 1985-86 would enable completion of the existing Rankine, Stirling, and Brayton engine programs, and would simultaneously enable DOE and/or its successor agency to initiate, conduct, and complete R&D efforts in engines, storage, receivers, collectors, and controls. Specifically, the $15-20 million per year effort would answer several of the questions highlighted in the "component status report" section (pp. 3-4) of my July 28, 1982 testimony. To wit:

Concentrator The largest subsystem of a parabolic dish module is the concentrator, a shallow dish with a reflective surface that tracks the sun to focus sunlight on a receiver. Tracking along two axes ensures maximum solar energy collection during the day. Seven and eleven meter concentrators have been built and tested under DOE and/or industry sponsorship since 1977.

The conventional optical configuration for a dish concentrator is a paraboloidal mirror. The paraboloidal shape may, however, be segmented into a number of individual reflecting facets, which may be curved or flat.

The ability to reflect and focus sunlight is a principal consideration in selecting materials and designs for dish concentrators. The classical optical material used is back-silvered glass. Reflective materials typically must be curved, the exact shape of the facets dependent upon the design of the concentrator. Materials other than glass, e.g., aluminum or aluminized mylar, can be shaped more easily, but such materials have lower reflectivity than back-silvered glass. Other technical questions being addressed are bonding of the concentrator layers, degrading of surface materials in the outdoor environment, and decreasing concentrator weight and cost while maintaining strength.

Receiver Because the receiver absorbs concentrated solar radiation at very high temperatures (2000°F), receiver materials must be developed that can withstand these and the potentially higher operating temperatures (up to 2700°F) of future dish systems. Several types of receiver have been developed and tested by DOE and industry since 1976. Additional research and development activities will concentrate on minimizing heat losses through the receiver opening (aperture).

Engines Three types of heat engines are being tested for use with parabolic dishes: Brayton, Rankine, and Stirling. Heat engine designs for solar thermal-to-electric dish applications must be adapted for use in different attitudes due to the varying sun angle from sunrise to sunset. However, key development issues are the achievment of high engine performance and reliability, and identification of operating requirements at the interface of the engine and receiver.

Storage For dishes providing thermal energy, periods of direct solar operation can be augmented by the addition of a thermal storage system. The storage media that has been most researched consists of oil/rock mixtures for use with the Rankine engine. Buffer storage (up to 1 hour) and intermediate storage (1 to 6 hours) can provide energy for dish systems during dark periods. Dishes operating in the Brayton or Stirling mode can be fitted with short-term thermal storage capacity (between the heat engine and receiver). The storage media will typically be a solid with high surface to volume ratios, e.g., ceramics, most frequently in a honeycomb configuration, when a Brayton or Stirling engine is used. These engines can be operated in a hybrid mode, where the engine runs on fuel, either fossil or renewable low BTU gas from biomass conversion, when sunlight is inadequate, providing a continuous source of electricity.

Controls Dish systems track the sun in two axes. Each dish in a collector field is adjusted individually to ensure that the optimal amount of sunlight is being focused on the receiver opening. This requires the use of a computer-based active tracking mechanism to determine and maintain accurate alignment. Additionally, the control must regulate the engine/alternator in response to changes in the load requirement. This can be handled by appropriate modulation of the energy supplied by the Solar Receiver and/or the burner in a hybrid system. Other safety, and start-up/shut-down functional considerations must be automated.

QUESTION: On Page 6 of your testimony you describe the advantages of the Brayton cycle engine for parabolic dish technology. What are the disadvantages? What problems need to be resolved?

RESPONSE: As acknowledged, the testimony does highlight certain of the advantages offered by Brayton turbines in parabolic dish systems. We are fortunate that the Garrett Corporation is developing two small turbines for high volume markets which are ideally suited for parabolic dish applications. There are few Brayton "disadvantages" per se; rather, there are technical development issues. For example, engine bearing, recuperator life, and dusting questions must be answered. These answers would help build the reliability and maintainability data base now lacking. The base would be complete once the full system test programs now planned have been conducted. In a related issue, cost estimates on production quantities of high temperature turbines are rather soft because of the lack of long term testing. The only perceived disadvantage is that projected efficiencies for small temperature turbines are somewhat lower (35-45%) than estimates for Stirling engines (40-50%).

QUESTION: Dr. Brown states in his testimony that parabolic dish systems are not likely to be as attractive to utilities as central receivers because of lack of storage and "the potential for high maintenance costs of a large number of small components." Could you comment on those observations?

RESPONSE: Dr. Brown's comment regarding storage paints an incomplete picture. The high temperature storage requirement associated with Brayton systems is indeed a more challenging technology problem than that associated with lower temperature systems but it is by no means insoluble. In fact, Sanders developed and successfully tested (in 1980) a combined storage/recuperator module for parabolic dish systems which shows promise for multi-module applications. Further, Brayton parabolic dish systems can easily be operated in a hybrid mode; i.e., designed to burn a variety of fossil fuels, such as biogas, during periods of low or no insolation. This minimizes the long term storage requirement. Another point on this issue might be made:

Various market studies indicate that parabolic dish systems appear to be as highly useful as peak load plants as they might be as base load plants. Multi-module parabolic dish power plants with 2 to 4 hours of storage would be ideal as peak load (late afternoon-early evening) plants in many parts of the Southwest. Further, the same studies indicate that the initial Brayton parabolic dish market may be in the remote site sector where battery storage and/or hybrid operation would be the most viable options for round the clock operation.

Contrary to Dr. Brown's opinion, parabolic dish systems may prove to be better for utilities for several reasons, among them the fact that multi-module dish plants feature highly redundant elements; i.e., scheduled or unscheduled shutdowns for maintenance of and/or repairs to modules results in output reduction by multiples of 20 KW rather than the substantial or shutdown of central receiver plants when one or more of the one, two, or three turbines becomes inoperative.

Extending the discussion to other plant components, maintenance costs associated with the concentrators (dishes) and heliostats (power towers) are rather similar in that the functions, technology and sizes are quite comparable. Further, at least in the parabolic dish case, receivers have been rather extensively tested and found to be a low maintenance item. There are dissimilarities in the respective power conversion assemblies but it is worth noting that steam turbine technology and gas turbine technology are very well known; in fact, gas turbine auxillary power units utilized in the aircraft industry (and of the proper size for parabolic dish systems) have life histories exceeding 60,000 hours. In sum, I do not feel that Dr, Brown's comment reflect the facts of the case.

**University of Houston**
**Central Campus**
Houston, Texas 77004

August 27, 1982

The Honorable Don Fuqua, Chairman
Committee on Science and Technology
U.S. House of Representatives
Suite 2321 Rayburn House Office Building
Washington, D.C. 20515

Dear Congressman Fuqua:

Attached is a response to a series of questions concerning Solar Thermal funding which you forwarded August 4. I wish to thank you for the opportunity of giving testimony at the hearing July 28 as well as responding to these questions. It is my view that solar thermal and specifically Power Towers can make a significant energy contribution as well as contribute to our national security. What is required for implementation is (1) maintenance of momentum gained since 1970 and (2) some incentives until the first ten full-scale plants are under operation within our electric utility structure.

Sincerely yours,

Alvin F. Hildebrandt

Alvin F. Hildebrandt
Director
Energy Laboratory

AFH:md

cc: Dr. Eugene Frankel

RESPONSES TO QUESTIONS - DR. ALVIN HILDEBRANDT - UNIVERSITY OF HOUSTON

Response to Questions

1. What do you believe is the level of effort required over the next few years to maintain an adequate solar thermal R&D program?

   As funding needs of current demos and pilot plants decline over the next few years the transfer of these funds to R&D will allow R&D to grow to the required level. As specific technologies advance beyond the R&D level in future years, special allocations for pilot plants and demonstration units should be made. I would recommend a funding level of about $60M per year for solar thermal R&D for the next five years. At the present about half would be for research and the balance for engineering testing. Solar Thermal is a developing technology that can make a significant continuing contribution to our energy resource in the future. Because the technology is relatively simple, opponents argue it should be left to industry. Not so. Engineering development is required. Nationally we are tending to fund research for systems that are very difficult and may never work well, rather than develop systems that assure a positive result. Nuclear fusion is a hope: solar thermal is workable. Solar thermal needs the same engineering consideration that nuclear fusion will absolutely need if feasibility is shown.

2. What do you believe the Federal Government should do in the next few years for solar thermal technologies not covered by your testimony, i.e. solar ponds and hemispherical bowls? Do you support the Salton Sea or Crosbyton demonstration projects?

   I do not support research in solar ponds because of limited applicability and because the Israelis have the technological lead. There are a number of negative factors such as excessive land use, environmental problems and corrosion factors. The hemispherical bowl has no prospect of economic competition with parabolic dishes or Solar Power Tower systems. The physical performance is poor and there is no broad industrial supplier or potential user base. I recommend canceling.

3. Do you believe the business tax credits for renewable energy systems should be extended to 1990 as proposed in H.R. 6735? Should they be made available to utilities?

   Absolutely yes to the first question. There is about $500-750M of activity required in the power tower technology to bring it into the full marketplace. Some fraction of that amount will have to be subsidized in the form of tax credits or guaranteed loans. In our present utility regulatory approach fuel costs can be passed through to the consumer but the cost of collecting solar cannot. Regardless of the long term value of solar to the consumer and the nation, the local utilities cannot be expected to develop experimental capital intensive systems with investors' money. Either tax incentives to third parties need to be maintained and even increased or reevaluate the requirements of the fuel pass through procedure. I would propose an energy pass through clause. I expect that fusion energy capital development, once feasibility is shown, will also face this problem. Concerning tax credits for utilities; they are of no value in present utility tax structure. Third parties are needed for at least the first ten full scale plants. The only way utilities could benefit is to permit them to sell tax credit for liabilities to other companies. This procedure would appear too controversial for utilities.

4. Do you believe that a federally funded repowering demonstration plant is needed for central receivers?

   If the Southern California Edison Initiative involving the incentives under #3 does not succeed by January 1, 1983, then a 50% government 50% utility cost shared demonstration is recommended. This is considerably less than that demanded by the breeder program and fusion program, both in percentages and dollars.

5. Could Solar One (Barstow) be used as a test facility for advanced receivers, advanced storage, and steam generator systems? Should it be? How difficult would it be to retrofit, say, a molten salt receiver, storage and steam generator system onto Barstow? How expensive?

   Yes, Barstow could be used as a test facility but should not be used for this for at least two years. The industry, manufacturers, and utilities are quite solid on this point. Let Barstow run and get running experience and life data. I believe that the necessary component tests can either be run at CRTF Albuquerque or by the addition of an on site tower at Barstow to be available two years from now. I sense that the industry would accept the component tests at CRTF. Note that Solar One could provide a peak flux of 2-4 $MW/m^2$ on a north facing receiver at the current receiver position. One could 1) add a second tower approximately 100m high south of the present tower, 2) at the south end of the present field (bad blocking of current heliostats) or 3) replace the current receiver. Proposals 1 and 2 would allow intermittent operations with the current receiver and system. Each would cost approximately $50M.

6. What level of effort will be required over the next few years to fund an adequate solar thermal fuels and chemicals program?

   I would recommend a research only budget in $M of:

| 1983 | 1984 | 1985 | 1986 | 1987 | 1988 |
|---|---|---|---|---|---|
| 5.0 | 7.5 | 10 | 10 | 10 | 10 |

   By 1985 one would expect to start a pilot or demo at some additional cost. This assumes an active program in high temperature materials and receivers be funded through SERI.

In conclusion I recommend that at least half of the research as well as engineering development be for funded projects in Industry and Universities. The remaining funds would be for funding researchers or management by government or national lab employees. Such an arrangement keeps a competitive mix and guarantees the technology will indeed be transferred.

ARIZONA PUBLIC SERVICE COMPANY
STA. 5629
P.O. BOX 21666 · PHOENIX, ARIZONA 85036

August 26, 1982

Dr. Eugene Frankel
Subcommittee on Energy
Development and Applications
Room B-374
Rayburn HOB
Washington, D.C. 20515

Dear Dr. Frankel:

I was pleased to be able to present testimony on July 28 before the House Energy Development and Applications Subcommittee and appreciate this opportunity to elaborate and clarify. My responses to Mr. Fuqua's questions are attached. I have also attached a copy of my biographical summary as requested in the invitation to appear before the Subcommittee. The situation was such that I was unable to submit it with my written testimony.

I hope that my testimony and responses project the impression that solar thermal technologies can make important contributions to the future energy supply of our Nation and that certain concepts can become commercial relatively soon. There is a valid critical role for the federal government of underwriting the risk in developing these new concepts to assure that these desirable energy producers become available.

Although there are a number of solar thermal concepts for different applications supported by various advocates, I believe that the solar central receiver is the most promising concept for economically converting substantial amounts of sunshine to electricity on a large scale. Compared to the other solar thermal technologies, the central receiver has the potential for having the most beneficial impact. It is also the one concept for which federal support is most crucial. The federal government therefore is urged to underwrite the risk of R&D by continued direct participation in engineering, hardware experiments and cost-shared demonstration.

If you have additional questions, I would be pleased to respond.

Sincerely,

Merwin L. Brown
Manager of Research Programs

cec

Attachments

## RESPONSES TO QUESTIONS - MERWIN L. BROWN - ARIZONA PUBLIC SERVICE CO.

*Question 1:*

*What do you believe is the level of effort required over the next few years to maintain an adequate solar thermal R&D program?*

A representative solar thermal budget for the years 1983 thru 1986 is presented on the attached table. Although I attempted to reflect input from experts involved in solar thermal development, I could not be all inclusive. I believe, however, that the total amounts listed are reasonably accurate. Note that the dollar amounts in this budget assume an inflation rate of about ~~8 percent~~ a year.

The monies budgeted for the central receiver R&D cover such activities as continued operation of Solar One, maintenance of existing test facilities, continued R&D of system components, and repowering. The repowering budget assumes that engineering is completed for two concepts in 1984. One of the designs is then selected and a repowering demonstration of about 60 MW is constructed with cost sharing by a utility. (See answer to Question 6 below for elaboration on cost sharing.) It was also assumed that the repowering construction will be completed in 1986 and at that point the need for federal participation should diminish significantly.

The systems using trough solar collectors are generally well developed and demonstrated. The amounts shown in this budget, therefore, reflect a federal role of funding basic materials R&D for items such as advanced coatings for thermal receivers and improved reflective surfaces for mirrors, and to complete data collection on existing demonstrations.

The dollars indicated for the dish technology are based on the assumption that federal assistance is focused on R&D for advanced electric conversion equipment proposed for dishes, such as Brayton and Stirling engines, and for high temperature receiver materials and improved reflective surfaces. Funds are also included to test this equipment. Furthermore, continued operation of the Shenandoah installation is included so that data can be obtained from the investment in place.

The dollars amounts suggested for solar ponds represent a federal support of basic R&D in salt gradient pond development. The line entitled "general" contains recommended funding levels for advance materials R&D, university investigations, and planning and assessment. It might be noted that the specific projects, Crosbyton and Salton Sea system field experiments, were not included in this budget. I discuss solar ponds and dish-type concepts in more detail in response to Questions 2 and 4 below.

## DOE THERMAL SOLAR
## BUDGET RECOMMENDATION
(millions of dollars)

| | 1983 | 1984 | 1985 | 1986 |
|---|---|---|---|---|
| Central Receivers | 36.7 | 42.5 | 80.8 | 42.7 |
| Troughs | 3.0 | -- | -- | -- |
| Dishes | 8.8 | 7.2 | 1.5 | 0.4 |
| Ponds | 1.0 | 1.0 | 1.0 | 1.0 |
| General | 5.2 | 4.8 | 4.0 | 3.0 |
| | 54.7 | 55.5 | 87.3 | 47.1 |

3% escalation applied

8-23-82

*Question 2:*

*What do you believe the Federal Government should do in the next few years for solar thermal technologies not covered by your testimony, i.e., solar ponds and hemispherical bowls? Do you support the Salton Sea or Crosbyton demonstration projects?*

Solar ponds have some special characteristics of interest. Relative to other solar thermal concepts, the collection system is quite inexpensive and storage is inherent in the pond. Unfortunately, the low electric conversion efficiency that results from the relatively low temperatures achievable by solar ponds offset these advantages. Therefore, as solar electric generators solar ponds should be given a low priority compared to some other solar thermal concepts. I believe, however, that there remains sufficiently enough unknown about salt ponds to justify a low level of R&D to attempt to maximize their beneficial aspects, especially for limited thermal applications. Therefore, basic R&D into the establishment of salt gradients and their stability, and investigation into low-cost salt and containment materials are probably justified until sufficient knowledge is obtained to make a definitive conclusion about salt pond technical and economic feasibility.

Although a very interesting and potentially successful solar pond project, the Salton Sea demonstration has questionable value as a nationally funded effort. Such applications as this one are very limited geographically in the U.S. because of the few number of suitable existing salt lakes in the U.S. Furthermore, there has been considerable advancement made in the Middle East, especially by Israel, in utilizing natural bodies of saline water. I therefore believe that much experience can be gained from what has already been done overseas.

In 1974, the hemispherical bowl utilized in the Crosbyton demonstration project was introduced to APS by the Meinel's of the University of Arizona in Tucson. At that time we were intrigued by the concept because it offered the advantage of fixing the reflective surface and requiring movement of only the thermal receiver to track the sun. At that time we believed that approach would result in a lower cost structure than for a system utilizing a tracking mirror. In addition to the hemispherical concept we also, about that same time, began a similar investigation on a fixed trough mirror developed by General Atomic.

*Question 2 (continued)*

After some preliminary investigations and hardware testing of these fixed mirror concepts, we encouraged the Electric Power Research Institute to fund engineering analyses of the two concepts deployed as a utility electric generator. The conclusions drawn from EPRI studies indicated that neither concept could likely compete with the solar central receiver. Both fixed mirror concepts suffered from a relatively low annual efficiency of solar collection due to cosine losses resulting from the fixed position of the collectors. The hemispherical bowl specifically appears to require more higher priced field labor than the central receiver. Two tudies[1,2] presented at the DOE Solar Central Receiver Semiannual Meeting, October 1980, published in SAND 80-8049, January 1981, concluded that the hemispherical bowl concept could not compete with the central receiver. With that background of information, I recommend that federal support of the Crosbyton project be reevaluated.

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[1] Apley, Walter J., "Assessment of Solar Options for Large Power Applications," Pacific Northwest Laboratory.

[2] Thornton, John P., "Comparative Evaluation of 1-10 MWe Solar Thermal Systems," Solar Energy Research Institute.

*Question 3:*

*Do you believe the business tax credits for renewable energy systems should be extended to 1990 as proposed in H.R. 6735? Should they be made available to utilities?*

In general, I do not believe tax credits are as effective in the R&D stage as direct participation by the federal government. Subsidies by tax credits do not provide the proper motivation to assure that they focus on the candidates most likely to be commercially successful. Direct participation by the government in underwriting the high risk R&D portions through the demonstration phase can provide greater selectivity and therefore effectively require less subsidy. When the concept is near commercial, tax credits might then be properly applied. Therefore, tax credits should be considered as a supplement to direct participation and not considered as an alternative to be implemented to the exclusion of direct R&D funding by the government.

For tax credits to be effective in many of the solar thermal concepts, especially the most promising of these, the central receiver, they will probably have to be made available through 1990. If adequate engineering, component hardware testing and system demonstration is timely completed by about 1986, then the central receiver should be at a stage of development to utilize tax credits. Since utilities represent the major market, it would be desirable if these tax credits were made available to them. It should be noted, however, that many utilities generally are not in a financial position to fully utilize these tax credits. If tax laws permit transfer of the credits to "third parties" through leasing or other financial arrangements, then these utilities could benefit from the tax incentives.

*Question 4:*

*Mr. Shine stated in his testimony that parabolic dish systems are not likely to be as attractive to utilities as central receivers because of lack of storage and "the potential for high maintenance costs of a large number of small components." Could you comment on those observations?*

The dish solar concentrator can produce the high temperatures required for a good efficiency of conversion of sunlight to electricity. By their nature, dish concentrators are relatively small, typically capable of collecting less than 100 KW of thermal energy per dish. The most economical approach for electric generation using these dishes appears to incorporate a small heat engine/electric generator, like a Rankine, Brayton or Stirling, into each dish concentrator. Thus each dish system becomes a quite small thermal electric power plant.

Because of the large number of high-temperature rotating machinery units required to make up a significant electric power plant, the operating and maintenance cost per unit of power could be quite high, compared to a similar sized power plant utilizing a single rotating machine. The ratio of number of rotating units for the dish concept to a single large turbine generator is between 1000:1 and 10,000:1. This situation has a high potential for adversely affecting the reliability and the cost of operation on a utility system.

Although storage is being investigated for the dish concepts, it has been characterized as a buffer storage of an hour or less. The longer term storage required to permit substantial capacity credit does not appear to be easily applied to a dish concentrator solar electric plant. Limited capacity credit results in limited economic value to most utilities because additional power plants must be built to give the utility the required capacity to supply power demands.

The dish concept might be economically viable for an industrial application or deployment as a small electric generator in applications remote from a utility grid or not requiring a firm power supply. Some utilities, especially those associated with small communities relying on oil-fired electric generation, might use solar dish power plants as fuel savers, provided their penetration of the utility grid is limited to prevent adverse affects on the optimized generation mix caused by the lack of capacity credit.

*Question 4 (continued)*

The dish concept does not, however, appear to be as attractive as the central receiver for large scale electric generation. The larger sizes of the central receiver concept are more appropriate for additions to the utility generation mix. Because of the ability to employ longer-term energy storage, solar central receiver power plants can receive capacity credit because utilities can depend on them as reliable electric generators. Our studies project that as the central receiver concept meets its cost goals it can economically compete with, and therefore displace, coal-fired generating plants that are operated to meet intermediate (cyclic) load demands. A 100 MW or larger central receiver would use a single steam turbine generator of relatively high efficiency. The maintenance of this one piece of rotating machinery should be lower than for the thousands of units used in a similar size dish power plant. In summary, through numerous studies, (Reference No. 1 in Question 2 above), we conclude that the central receiver concept is more promising for large scale economical generation than the dish concept.

*Question 5:*

*Could the repowering demonstration you recommend on page 9 of your testimony be financed by third party ownership and use of the business tax credit?*

There is a possibility that a repowering demonstration could be financed, at least in part, through third party ownership and the use of business tax credits, but based on our experience and what we observe nationally, we do not believe that "third parties" could and would totally finance a project of this financial magnitude and risk.

Although the studies and hardware tests performed to date project a very attractive economic picture for the central receiver, there remains some uncertainty in the ultimate efficiency of the system, the lifetime of components, the operation and maintenance costs, and the construction costs, especially for heliostats and the cost of money used for construction. There is also uncertainty in the future value of the fuel displaced over the economic lifetime (30 years) of the plant. Because of the relatively large investment required for a commercially scalable demonstration, even small failures to meet expectations in performance or costs could involve rather large sums of money. This situation makes it difficult to attract third party financers that can supply the total funds needed, take advantage of the rather substantial tax credits and accept all the risk. After the first commercial scale plant is built and operating, then the uncertainties are largely removed and private industry can accept the risk and provide financing without government assistance.

Despite these difficulties, APS intends to continue to investigate using third party financing to the degree possible. This task is included in our third phase, Preliminary Engineering, cost-shared contract, which we are currently negotiating with DOE. We may be able to arrange third party financing that can at least use tax credits to reduce the portion of federal direct participation required to underwrite risks inherent in a first-of-a-kind facility.

*Question 6:*

*The $145 million figure you give on page 9 for a 60 MW repowering plant is considerably lower than previous estimates given to this Subcommittee just last year. What makes you think the plant can be built at that lower cost? How confident are you that 50 percent utility cost sharing can be achieved?*

The previous higher cost estimate referred to in this question is likely one for a larger repowering size of 110 MW. The apparent lower cost, therefore, is the result of reducing the plant size to 60 MW in a subsequent engineering study. In response to the second question, the degree to which a utility can justify cost sharing is limited to its perceived economic value. The 50 percent cost sharing level is a goal achievable under near optimum conditions. A large number of factors govern the ability of a utility to justify cost sharing approaching this level. While some of these factors are immutable, many can be improved by continuing government support of engineering studies and hardware experiments. These activities are required before a cost sharing level can be determined and expressed with confidence. These responses are expanded below.

The $145 million figure for the Saguaro 60 MW solar repowering plant came from the Advanced Conceptual Design APS performed for DOE and that was published in the final technical report, DOE/SF 11570-2, April 1982. That figure is given in the testimony in 1983 dollars and assumes a heliostat cost of $263 per square meter. In past testimony presented to the Energy Development and Applications Subcommittee on Science and Technology, March 12, 1980, by Mr. D. L. Broussard, vice president of APS, a figure of $163 million in 1980 dollars was given for the cost of the Saguaro solar repowering project. This cost estimate was for a 110 MW solar repowering level for Saguaro that was examined in an earlier conceptual design funded by DOE, completed in July 1980, and published as a final technical report, DOE/SF 10739-2. The number that Mr. Broussard presented was a preliminary number that was derived during the course of that study. The final number at the completion of the effort was $166.8 million. The assumed cost of heliostats was $230 per square meter. Therefore, the apparent lower cost presented in my testimony is the result of reducing the size of the repowering facility and refining cost estimates in a subsequent study.

In the Conceptual Design completed in 1980, we evaluated a number of different repowering levels. Based on a minimum busbar energy cost, there was a slight advantage to completely repowering the 110 MW oil-fired unit at Saguaro. In the subsequent study, the Advanced Conceptual Design completed in 1982, we returned to a 60 MW level because it became evident that, in spite of the slight energy production cost advantage of the 110 MW size, the smaller investment required for the 60 MW size was more consistent with the perceived risk to all parties involved in this first-of-a-kind project and with the availability of money in an extremely tight market restricted by high interest rates. The 60 MW level is seen as the smallest commercially scalable size for our system.

The 50 percent utility cost sharing for a repowering project should be considered as a goal achievable under optimum conditions. We arrived at this level using the results of our Advanced Conceptual Design completed in 1982 already discussed above. The optimum situation assumes that the plant operated at a plant capacity factor of .285 and that all of the electrical energy produced displaced oil that would have been burned in plants on our system. To achieve these conditions, the plant would have to operate at an overall efficiency of conversion from sunlight to electricity of 23 percent.

It is difficult at this time to express a confidence factor for a utility to be able to cost share to this degree. It largely depends on how confident the utility is in predictions of performance, fuel savings, costs of construction and operation and maintenance, and availability of sunshine and the plant. The engineering design and component testing activities currently underway or proposed as part of the federal/industry R&D program will have a great impact on the confidence of a utility to commit to the cost sharing. Other, mostly immutable factors peculiar to an individual utility that must be considered are such things as the quantity and quality of sunshine available, the generation mix, i.e., the amount of oil that is saved compared to other cheaper fuels, like coal and nuclear, displaced, and the degree of capacity credit that can be attributed to the solar facility. Capacity credit expresses the degree to which a power plant added to the system can reliably contribute to the utility's ability to meet power demands.

The repowering concept is the lowest cost and risk alternative to demonstrate the central receiver. However, solar repowering is limited to fuel savings without any capacity credit. What this means is that the solar energy may save some oil or coal that normally would have been burned, but it does not save the utility from having to add additional generating capacity to meet future growth needs. Repowering of an existing power plant does not add new capacity to the system. This factor is significant for a utility like APS that uses mostly coal and nuclear but little oil.

In order to increase the economic value of a solar plant, we investigated the feasibility of building a new solar facility in lieu of a conventional power plant. Using data from the Advanced Conceptual Design completed in 1982, we performed an economic evaluation for the Saguaro repowering solar facility built as a stand-alone plant with its own turbine generator system. The evaluation predicted that this new capacity addition could displace future intermediate-load coal plant capacity on our system. The results of this study for a commercial scale stand-alone 110 MW plant are presented in my testimony on pages 9-10. Because of the fuel savings and capacity credit, the optimum cost sharing was calculated to be as high as 80 percent, but it should be recognized that for a stand-alone demonstration the total investment required and the risk involved would both be higher than for repowering. Again, the utility's particular situation and the confidence in these predictions will greatly affect its ability to justify cost sharing towards this goal.

At this time, APS is not in a position to decide whether the Saguaro project should be built as a repowering facility or as a stand-alone. Our on-going engineering efforts toward a repowering configuration, however, are valid in either case. Only after we have done more engineering and have obtained the experience of on-going and proposed component testing can we determine which configuration we would choose at Saguaro and to what degree we could justify cost sharing.

In the solar thermal budget that I presented in response to Question 1 above, I assumed a utility cost sharing of about 20 percent. There are a number of factors that could decrease the government's participation and increase the percentage of the utility cost sharing closer to the optimum conditions discussed above. Continued and future support of engineering and component hardware experiments would be extremely valuable in increasing the confidence of the utility in the performance of the technology and its economics. Any efforts that could reduce the cost of heliostats from about $260 per square meter for a repowering demonstration would, of course, increase the percentage of the cost that would be economical. An improved national economy having lower inflation and interest rates would further improve the utility's ability to cost share. Arrangements whereby the government provided energy cost guarantees should allow a utility to commit the maximum cost sharing up front. Lastly, as discussed above, tax credits may prove helpful in some cases.

In summary, a utility can help fund the cost of this development to the degree that the facility has perceived economic value. It should be recognized, however, that a utility is severely constrained by regulation from committing large amounts of funds to high risk investments. Utility regulatory entities are careful to protect the rate-payer from unknown cost burdens and economic risk, especially a risk of national nature that should be shared by the general population. The relatively low return on investment allowed by these regulatory entities further restricts the ability and reduces the motivation of financial entities to invest in high risk activities. Government participation by underwriting the risk in the development of this technology is justifed because the valuable results of studies, tests, and demonstrations will be available to the public at large. The product can be deployed in a reasonably broad geographic region and will save valuable fuel that will become more available for the Nation as a whole.

*Question 7:*

*Industry testified to us this Spring that they only need funds for detailed design of a solar thermal repowering plant. How effective would that be if we can't find the resources to build a demonstration plant?*

Termination of the federal program prior to demonstration would result in a high probability that this potentially valuable concept will not materialize in the foreseeable future. Each step taken in the engineering design and component hardware development testing increases the probability that the central receiver concept will ultimately be deployed commercially. However, the most significant activity in assuring that the solar industry will make the necessary investment to commercially produce the components of a solar central receiver and that the utilities will risk their investment in the construction of a commercial plant is the demonstration of a commercially scalable, advanced technology plant. Even with the completion of detailed engineering and testing of components at facilities like the one at Albuquerque, the jump required to build a demonstration plant entails considerable risk.

There is an attempt underway to have a commercial scale plant built taking advantage of tax credits and third party financing. APS supports this effort because, if it is successful, it would represent a major demonstration, provided that a commercially scalable, advanced technology system is chosen. However, as discussed in response to Question 5, this approach is uncertain and we should not abandon the industry/government R&D program to develop the central receiver. The efforts currently underway in the DOE program and as planned for the next few years are applicable to any future activity regardless of the outcome of this attempt to fund a major facility with tax credits alone. During this next year, we should have a strong indication of whether or not this approach will be successful. In the meantime, the federal government is strongly urged to work toward a national program that involves at least one major demonstration of the solar central receiver concept.

# APPENDIX II

## PROCEEDINGS: WORKSHOP ON RESEARCH AND DEVELOPMENT NEEDS FOR SOLAR THERMAL SYSTEMS FOR THE 1980'S

### RESEARCH AND DEVELOPMENT NEEDS FOR SOLAR THERMAL SYSTEMS FOR THE 1980s

### INTRODUCTION

A workshop was held on May 5, 1982, at the Solar Energy Industries Association headquarters in Washington, D.C., for the purpose of defining, in broad outline, the major thrust that, from the viewpoint of the attendees, the Federal Government should take in research on and development of solar thermal systems in the 1982 to 1990 time period. The meeting was attended by 18 people representing 17 different organizations. The list of attendees is given in Attachment I.

### WORKSHOP METHODOLOGY

The agenda for the meeting consisted first of a series of presentations (see Attachment II) on the results of some of the prior meetings, conferences, and surveys that had been held on this basic issue or a closely allied topic. It was recognized before this meeting was scheduled that numerous attempts to define a solar thermal program had already been made, and it was wise to draw upon the results to the maximum extent possible. Most of the prior meetings of which the attendees were aware dealt principally with planning for the application of solar thermal concepts to the production of fuels and chemicals (the so-called sunfuels program). Although such an application of solar thermal concepts was determined by this workshop to justify a major thrust, it is not necessarily the only one, nor is it entirely clear, at this time, that such an application will ultimately be economically viable.*

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*For this meeting, R&D pertaining to sunfuels was arbitrarily defined in terms of studies, experiments, and tests in which a chemical process occurs in a receiver/reactor located at the focal point of the concentrator, whether it is a central receiver, parabolic dish, parabolic trough, or some similar device. It is readily recognized that processes for the production of fuels and chemicals can equally well, and perhaps, in the long run, be more economically carried out, in some cases, by producing heat energy in the receiver of the solar system and transporting this energy to another location for carrying out the chemical process. The latter approach is arbitrarily defined by this workshop to fall in the category of R&D on industrial process heat systems.

The second part of the agenda consisted of prepared comments by representatives of two major chemical companies and was followed by prepared comments and recommendations from several individuals representing the manufacturing industry, universities, and the national laboratories. The workshop concluded with a general discussion and some recommendations.

In order to expedite the workshop proceedings, a "straw man" list of potentially important, long-term, R&D thrusts was prepared and presented at the beginning of the meeting. This list is given in AttachmentIII and served as a standard from which items could be withdrawn or to which items could be added as the workshop progressed.

## WORKSHOP RESULTS

The basic list of R&D needs for solar thermal systems for the 1980s, as contained in the straw man list of Attachment III, was left fundamentally unchanged insofar as broad outline was concerned; however, one additional topic was identified and added to the list of R&D thrusts. This topic is the research and development needed to apply solar thermal processes to the disposal of waste materials.

Although there was general agreement that the topics listed (plus the waste disposal concept) represented the R&D thrusts that the Federal Government should follow in R&D in solar thermal for the 1980s, there was an indication that the list should be structured in a more logical fashion. For example, research on chemical heat pipes applies to the production of chemicals, fuels, industrial process heat, and electricity. Therefore, it falls in the category of a means for achieving an end product, rather than a product itself. The production of a fuel, on the other hand, is an end product which can be achieved by various solar thermal methods. With this logic in mind, the consensus of the workshop attendees seemed to be that the list should be reorganized.

The tentative conclusion of the workshop is, therefore, that the Federal Government, during the balance of the 1980s, should support research on and development of solar thermal systems that:

1. Produce liquid and gaseous fuels from nonrenewable and renewable feedstocks
2. Produce chemicals, with special emphasis on reduction of energy costs in the production of current chemical products
3. Show promise for effecting both near and long-term improvement in the cost of energy and/or efficiency in the production of electricity and process heat
4. Lead to cost effective unique methods for disposal of waste products.

Principally within Category 3, but also within Categories 1 and 2 to some extent, Federally-sponsored R&D work should emphasize the following technologies and/or processes:

1. Energy storage
2. Chemical heat pipes
3. Component and subsystem cost reduction and efficiency improvement projects
4. Solar ponds
5. Photon-induced processes
6. Selected exploratory experiments that potentially offer long-term payoff in terms of reduction of energy costs, conservation of fossil energy resources, improvements in the quality of the environment, and reduction of foreign oil imports

In order to be able to carry out a meaningful R&D program for the 1980s and beyond, it was the consensus of the workshop attendees that test facilities are absolutely essential. Therefore, any R&D planning must include the financial resources to maintain and operate selected test facilities. As a minimum, these facilities would be the Advanced Component Test Facility at the Georgia

Institute of Technology; the Central Receiver Test Facility in Albuquerque, New Mexico, and the parabolic dish test facility at Edwards Air Force Base.

## COMMENTS

Comments were made and extensive discussions were held by the attendees on most of the above-listed R&D recommendations. Some of the comments,which are important in understanding the intent of the attendees insofar as implementing an R&D program for the 1980s is concerned,follow.

### General

There was a strong recommendation that the undertaking of the longer-term R&D work by the Federal Government should be done in consonance with the completion, by the Federal Government, of several on-going technology programs that are close to being turned over to the private sector. In particular, the central receiver, parabolic trough, and parabolic dish programs, as described in the STEA budget recommendation for FY 1983 and beyond, must be completed under cost sharing arrangements, as the longer-term R&D work outlined above gets underway. In fact, the goal of Federally sponsored R&D work must, in the viewpoint of many attendees, be to achieve a state of readiness in which a given technology can be taken over by the private sector,and, thereby, be made available as a viable energy option at the earliest possible time. Thus, the recommendations made above for long-term R&D for the 1980s must not be construed as a recommendation that the Federal Government abruptly delete support for the three technologies which are in the process of being taken over by the private sector. These three technologies, and,hopefully,others that will follow from long-term R&D projects, must be phased out in a logical, timely manner in accordance with the ability of industry to accept and complete final development and to commercialize.

### Production of Liquid and Gaseous Fuels

Research and development of methods for producing liquid and/or gaseous fuels from both nonrenewable and renewable feedstocks is an important thrust for the Federal program. In particular, the production of hydrogen by means of some form of thermochemical or combination thermochemical/thermoelectric water splitting appears to be a goal toward which the program should be directed in the very long term. Whether or not the production of hydrogen by these processes will be cost effective relative to such approaches as conventional or advanced electrolysis using solar thermal electric systems or such approaches as HTGRs and fusion cannot be determined at this time. The potential payoff appears to merit R&D in the 1980s, some of which should be directly applied to resolving the potential economic viability as well as the technical feasibility.

The thrust of this R&D requires, in the opinion of many attendees, a specific approach, however. This approach is to conduct the R&D program in such a way that it can potentially have near-term benefits for the U.S. chemical industry. For example, in selecting receiver/reactor tests which might lead to establishing the technical feasibility of a thermochemical water splitting process, one should select processes and designs that might, at the same time, be adopted by the U.S. chemical industry for application to the production of current chemical products. Thus, without losing sight of the goals, the R&D program should emphasize research on the technology base, and not emphasize. initially,a specific thermochemical process. The suggestion has been previously made, along these lines, to develop receiver/reactors which contain opaque tubes which accommodate gaseous,liquid,and solid feedstocks; receiver/reactors which contain windows and are able to handle gaseous, liquid, and solid feedstocks; and receiver/reactors which are windowless and are able to handle liquids and solids. Receiver/reactors of these types would apply to a wide variety of current chemical processes and ore processing systems and are also key steps in the development of many potentially viable thermochemical water splitting processes.

Also deserving R&D expenditures, but to a lesser degree, would be work on splitting of $CO_2$ to form CO, where the source of $CO_2$ would be carbonate rock or stack gases. Also falling within this category of R&D would be studies of methods of producing fuels from nonrenewable feedstocks if the process showed a potential for energy cost reduction or significant conservation of fossil resources.

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## Production of Chemicals

The workshop did not specifically discuss the advisability of doing R&D on chemicals. The importance of this application was evident, however, from the comments made concerning the recommended approach for solar thermal R&D on fuels production---namely that the technology developed should be of benefit in the near-term to the chemical industry, if possible. The cost of energy used in the production of chemicals is a very important factor in the industry today: profit margins frequently fall within the magnitude of the size of that fraction of the cost of the product that goes into energy. Thus Federally-supported R&D appears to be justified until the technical and economic merits of this application can be established.

## Performance and Cost Improvements

Although the parabolic trough technology is essentially in a commercial stage (some tax credits are still necessary) and although the dish and central receiver technologies are close to commercialization, (limited technology development and tax credits needed) all three technologies can benefit, in the long term, from basic engineering research on components and materials. In addition, some of this research would be necessary to solve problems in the application of solar thermal systems to fuels and chemicals. Specific examples of the component R&D that should be Federally supported are:

1. High temperature ceramic receivers for dishes and central receivers;
2. low cost concentrators for dishes and troughs and low-cost heliostats for central receivers;
3. sodium and salt steam generators;
4. improved, advanced sodium, salt, water, and gas cooled receivers;
5. high temperature windows; and
6. improved optical materials

There are, of course, other examples of specific R&D tasks that lead to improvements in performance of solar thermal systems.

Technology R&D

The six categories of R&D tasks that the workshop attendees recommended in the area of technology or process development in support of end-product-oriented R&D work are more or less self explanatory. A few comments regarding energy storage, chemical heat pipes and photon-induced processes need to be emphasized, however.

The attendees who represented the chemical industry emphasized at the workshop the importance of 24 hour per day operation of chemical processes. Although some chemical production processes could probably be adapted to accept cyclic operation, many of them must be kept operating on a more or less continuous basis to maintain equipment lifetime. This situation clearly indicates that energy storage in solar thermal systems is going to be a critical factor in long term economic viability. The impact of solar thermal on the reduction or stabilization of energy costs will be considerably enhanced if long-term, cost effective energy storage systems can be developed. Thus it is the consensus of the attendees that Federal support of this aspect of solar thermal R&D is justified and has a high priority. The emphasis should be placed on those concepts that can provide energy at low cost for periods of from 20 to a few hundred hours and at approximately constant temperatures from several hundred degrees Fahrenheit to roughly 2000°F, depending upon the application.

Although the chemical heat pipe concept has been studied in considerable detail in relation to more conventional heat sources, this method of transporting energy from one place to another appears to justify Federal R&D support in the solar thermal area. A rather promising application of the chemical heat pipe, an application that was first suggested by Dr. Alvin Hildebrandt of the University of Houston,involves a solar thermal heat source applied to a so-called "heat utility" which would supply heat energy via a chemical heat pipe in the same manner that an electric utility supplies electrical energy. For example, a solar system surrounded by or in the vicinity of an industrial complex is used to reform methane catalytically at a temperature of around 1600°F in order to form CO and $H_2$. These gases are piped several miles to the various industrial plants in the area when the gases are catalytically recombined to give up heat energy. One of the key features of this scheme is that each industry can, to some extent tailor the heat energy contained in the gases to meet his particular thermal demand as well as to meet specified conditions as to temperature and pressure. The heat energy derived from the catalytic recombination reactors can be used to heat air or water or to form steam, for example, depending upon the particular process or processes being carried out at the industrial plant.

There has been considerable debate as to the level of R&D effort that would be justified in the area of photon induced processes insofar as solar thermal systems are concerned. It is generally agreed that direct photon energy would not contribute substantially, if at all, to most processes under consideration for base chemical or fuel production. Furthermore, where the photo-energy does inter directly in the process. optical filtering to screen out wavelengths that do not contribute to specific photon interactions would probably be necessary in practical systems. Thus filters that can accept concentrated beams must be researched. Although these situations pose substantial problems, Federally supported R&D in this area is felt to be justified at this time principally in the area of determining the potential, if any, that exists in photon enhanced proceesses for solar thermal.

Attachment I

SOLAR ENERGY INDUSTRIES ASSOCIATION Suite 800 1001 Connecticut Avenue, NW Washington, DC 20036
SEIA

## SEIA WORKSHOP

May 5, 1982

| | | |
|---|---|---|
| F. Norman Christopher | Olin Corporation | 203/356-3583 |
| R. E. Smith | Olin Corporation | 202/331-7400 |
| L. L. VantHull | University of Houston | 713/749-1154 |
| R. A. Cassanova | Georgia Tech. EES | 404/894-3589 |
| R. S. Wishart | Union Carbide Danbury | 203/794-7048 |
| V. C. Truscello | JPL (Pasadena, CA) | 213/577-9367 |
| E. Frankel | House Sci. & Tech. Comm. | 202/225-3975 |
| Barry Butler | SERI | 303/231-1104 |
| Mel Bowman | Los Alamos | 505/667-1291 |
| Cliff McFarland | DOE STT | 202/252-5584 |
| Otto Kirchner | Boeing | 703/558-9622 |
| Patrick J. Eicker | Sandia Natl Labs | 415/422-3115 |
| Joel Weiss | Acurex Solar | 703/276-9066 |
| Tom Springer | Rockwell International | 213/700-4313 |
| Carlo La Porta | SEIA | 202/293-2981 |
| Dinesh Kumar | Pre-Systems Services | 703/998-0931 |
| Daniel J. Shine | Sanders Associates | 603/885-2970 |
| W. H. Percival (B. Washom) | United Stirling | 703/549-7174 |

Attachment II

# AGENDA

## WORKSHOP ON R&D NEEDS FOR THE 80'S

May 5, 1982
SEIA Headquarters, Washington, D.C.

1. Review of Prior Meetings, Workshops, and Conferences Pertaining to R&D in Solar Thermal

| | |
|---|---|
| - Gettysburg Semi-Annual (Nov. 3-4, 1981) | L. Vant Hull (U. of H.) |
| - Users Association Workshop (Sept. 1978) | R. Cassanova (GIT) |
| - JPL Workshop | T. Springer (Rockwell) |
| - Solar Thermal Program Advisory Panel | T. Springer (Rockwell) |
| - Series of Sunfuels Meetings | P. Eicher (SNLL) |
| - Sunfuels Technology Development Project | T. Springer (Rockwell) |
| - Industrial Research Institute Survey | T. Springer (Rockwell) |

2. Comments from Fuels and Chemical Industries
    - R. S. Wishart, Union Carbide
    - N. Christopher/R. Smith, Olin Corporation
3. Other Attendees' Viewpoints
    - B. Butler, SERI
    - D. Shine, Sanders
    - J. Weiss, Acurex
    - M. Bowman, LASL
    - O. Kirchner, Boeing
    - C. McFarland, DOE
    - R. Cassanova, GIT
4. Discussion and Recommendations

feh:723

Attachment III

## POTENTIAL LONG-TERM R&D THRUSTS

- Production of Fuels (processes occur in receiver)
  - From nonrenewable sources
  - From renewable sources
- Production of Chemicals
- Solar Ponds
- Chemical Heat Pipes
- Energy Storage
- Photon Processes
- Technology Improvement Program
- Exploratory Experiments
- Technology Development (generic to fuels, chemicals, and IPH processes)
- Others?

# APPENDIX III

## STATEMENT BY RUSSELL L. SCHWEICKART, CHAIRMAN, CALIFORNIA ENERGY COMMISSION

### Introduction

My name is Russell L. Schweickart and I am Chairman of the California Energy Commission (CEC). Thank you for the opportunity to present this statement on California's need for continued federal support of solar energy research and development. In particular, the California Energy Commission (CEC) urges you to fund the federal share ($1 million for FY 83) for the 5 megawatt (MW) Salton Sea Solar Salt Pond Project in southern California. This prototype 5 MW electric generating facility is to be funded cooperatively by the CEC (25%), Department of Energy (50%), and the Southern California Edison Co. (25%). The purpose of this project would be to obtain hands-on experience in the design, construction, and operation of a solar salt pond generating facility that would serve as the foundation for the design and construction of a 600 MW commercial generating facility at the Salton Sea. It would also establish a technical basis for the use of this technology as an energy source for applications in other parts of the country.

### Background

California has recognized the vulnerability of the state and the country to oil shortages and escalating oil prices. Accordingly, California state agencies, through policies, energy efficiency standards, and financial incentives, have encouraged California businesses, industries, and citizens to use alternative energy resources such as solar energy, whenever practical, as a replacement for oil-generated electricity.

One resource currently under development in California, for which a continuation of federal assistance is critically needed, is the solar salt pond. This technology traps solar energy in the salt concentration gradient of a thermally stratified body of water. Hot brine from the bottom of the solar pond is pumped to an evaporator, where a fluid such as freon is vaporized. The vapor flows under high pressure to a turbine which in turn spins an electric generator. The vapor then travels to a condensor where cooler water from the top of the solar pond condenses it back to liquid and the cycle is repeated. The stored heat energy is used to vaporize organic fluid (in a closed loop system) which drives the turbine-generator producing electricity. The concept of developing artificial solar ponds, conceived in the 1950's by Israeli scientists, was expanded in 1960 to include naturally occurring large salt water bodies such as the Dead Sea and the Salton Sea. Several experimental facilities were built at the Dead Sea, ultimately leading to the construction of a 5 MW power station, expected to begin operation this year.

During 1981, The California Energy Commission and Southern California Edison sponsored and completed a feasibility study "Solar Salt Pond, Electric Power Generation Potential at the Salton Sea". The Salton Sea was found suitable for location and expansion of a commercial size facility composed of 20 to 50 megawatt modules with an ultimate generation potential of 600 megawatts. It was concluded that a 5 MW demonstration research facility was a necessary prerequisite to a commercial undertaking to obtain cost optimization, operation, and performance data.

With the participation of the federal government and private industry, California has already made significant progress toward the development of this technology. Our combined efforts are now directed towards constructing a 5000 kilowatt (5 MW) demonstration research pilot plant to be located on US Navy property at the Salton Sea in southern California. If the 5 MW demonstration facility is constructed by the late 1980s and is closely followed by a larger commercial-sized facility (20-50 MW), the technology could be in commercial operation by the early 1990s.

The Department of Energy (DOE) has been an active partner in the preliminary studies that have resulted in highly positive technological feasibility and environmental assessments. DOE is now funding 50% of the preliminary engineering and cost optimization study for this 5 MW plant, and the California Energy Commission and Southern California Edison are each funding 25% of the $1 million study. This contract is expected to be completed in August 1983, at which time a decision will be made on the construction of the 5 MW R&D facility. The federal government's assistance is needed for the continuation of this preliminary engineering and cost-optimization study into FY 83 and for the construction of the pilot plant. About five years of testing at the free Naval Parachute Test Range site would provide the information necessary to scale up the project to commercial size at the next order of magnitude.

Although solar pond technology has been studied for over 20 years, it has only recently become feasible for application to large-scale energy production. The first experimental ponds were developed in Israel, at the Dead Sea by Ormat Turbines Ltd. (Israel). Ormat's research pond, completed there in December 1979, has produced 150 kilowatts of electricity. Ormat is now developing its own 5 megawatt facility. Much can be learned from this ongoing experience. However, the Dead Sea brine concentration is almost another order of magnitude, 280,000 parts per million (ppm) versus 37,000 ppm at the Salton Sea. A different set of issues is involved at the Salton Sea in determining methods of accelerating brine concentrations, while maintaining the brine in solution. Hydraulic and thermodynamic behavior management of thermally stratified ponds is the key to commercial development. Methods for maintaining water clarity and suppressing waves also need to be improved along with instrumentation and controls. The Jet Propulsion Laboratory will provide the necessary coordination between the project sponsors, and Architect-Engineer, the system designer, and equipment suppliers.

The California Legislature has authorized the Salton Sea Solar Pond feasibility project funds, and has provided for continuation of the project support in fiscal year 1983. The Legislature has provided this fund support for the project, recognizing that it is jointly sponsored by the Federal Government and private industry. Concurrently, the California Energy Commission in a joint effort with the United States Navy is preparing an Environmental Impact Statement/Environmental Impact Report for the project.

Once the Salton Sea Pilot Plant demonstrates that this technology can be placed in a commercial status, the construction of commercial plants could be funded privately by utilities or other interested parties.

## Need for a Demonstration Facility

Before this technology can be made commercially available, the 1:10 scale 5 MW pilot plant is needed in order to:

- Provide the engineering scale-up parameters required for commercial size (50 MW) equipment,
- Provide the hydraulic and thermodynamic data on the behavior of thermally stratified ponds required for commercial design,

- Provide the design and operational data feedback for a commercial facility design,
- Serve as a test bed for the daily collection of data and the monitoring of meteorological variations/impacts,
- Establish the system instrumentation and control requirements,
- Establish the water treatment and clarify maintenance requirements, and
- Establish the wave suppressors design/requirements.

## Benefits of Solar Salt Pond Energy Technology

There are significant environmental and economic benefits associated with the deployment of the solar salt pond power generating technology, which include:

- The technology does not produce air pollutants, waste products, or divert fresh water from other uses;
- A commercial facility would reduce the salinity in the Salton Sea. High salinity is threatening the existence of many of the species inhabiting Salton Sea, because of 4 million metric tons of salt received each year. Similarly, bodies of water in other parts of the United States could be protected from damaging increases in salinity;
- The system is capable of generating electricity day and night during all seasons;
- Construction costs for a 600 MW commercial facility are expected to be comparable to coal-fired or nuclear power generating systems. (A commercial facility at the Salton Sea with a 30-year life could be privately constructed at a cost of about $1800 per kilowatt of installed capacity (1980 dollars)).
- A 600 MW commercial facility could displace up to 8 million barrels of oil per year (potential capacity at the Salton Sea);
- A 600 MW commercial facility could avoid deterioration of air quality caused by the yearly combustion of 8 million barrels of oil (the system uses no fuel);
- A 600 MW commercial facility could save the rate payer an average of $300 million in fuel bills per year, based on current 8¢ /KWH fuel costs (without fuel price escalation);
- The total savings over a 30-year facility life (1990-2020) could be over $8 billion in avoided fuel costs, even assuming no escalation of the current fuel price and allowing for construction costs.

California is not the only state that can use and benefit from this technology. With financial assistance from the United States government, the California solar pond experiment will provide technical data that can be used in the design and deployment of solar pond facilities in other parts of the country.

According to a Jet Propulsion Laboratory study "Regional Applicability and Potential of Salt-Gradient Ponds in the Unted States" (1982), in the year 2000, potentially 580 million barrels of oil could be displaced per year from electrical production by solar ponds in the Southwest, Salt Lake, Gulf Coast, and Red River areas. A minimum of 920 million barrels of oil per year could be displaced in direct heating uses by solar ponds in those areas plus in the Black Hills, Pacific Northwest, Atantic Northeast, Great Lakes, and Tennessee Valley. With the exception of Alaska, solar ponds could provide thermal energy at sufficiently high temperatures for space and water heating of building clusters in all regions of the U.S. Solar ponds could also lend their thermal, mechanical, or electrical energy applications to desalinization and a variety of agricultural uses, such as irrigation pumping, crop drying and space conditioning.

## Conclusion

It is my conclusion that significant benefits can be derived from the development and deployment of solar salt pond technology in various parts of the United States. Whether or not these benefits will be realized depends on the successful completion of the California 5 MW Solar Pond demonstration facility at the Salton Sea. I, therefore, urge your support of continued federal funding for this project.

RUSSELL L. SCHWEICKART
Chairman, California Energy Commission

28 SEPTEMBER 82
Date